Indo-British Symposium on Climate Change, 15-17 January 1992, New Delhi

Global Climate Change

Science, impacts and responses

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MESSAGE

There is wide agreement among the scientific community that the Earth's climate will probably change over the next few decades, as a result of human activities, with serious implications for mankind. Yet it has not been possible to predict with adequate certainty the precise effects of this change, although there are reasons to believe that these will be considerable and adverse.

Clearly, research into the myriad aspects of global warming must intensively cover the chemical, biological and social factors that affect the environment of the Earth and the people who inhabit this planet. Moreover, tackling climate change effectively will call for major and concerted responses from all countries. A key feature of future action will be increased public awareness, so that all of us can contribute to tackling the adverse implications of climate change, as well as arresting further damage.

In this context, I would like to congratulate the British Council for organizing the Symposium on Climate Change last January. I had the pleasure of addressing it, and am now pleased to learn that its proceedings have been compiled and are being published.

I am sure that this compilation will encourage informed debate and form an authentic reference base for a wide spectrum of views, resulting in greater understanding of the various aspects of the subject, and also lead to co-ordinated scientific research.

(KAMAL NATH)

NEW DELHI
20th April, 1992.

From the High Commissioner
Sir Nicholas Fenn

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6 APRIL 1992

INDO-BRITISH SYMPOSIUM ON CLIMATE CHANGE

It gives me great pleasure to see the publication of the Proceedings of the Indo-British Symposium on Climate Change which was held in New Delhi, 15 - 17 January 1992.

This was the first such event to be organised between Indian and British experts and I know how much interest it aroused. I believe that it was timely in view of the forthcoming United Nations Conference on Environment and Development to be held in Brazil in June. Informed debate increased our understanding both of global warming and of each other's perceptions of the crisis. This in turn has allowed us to move forward in our international efforts to manage the issue.

I extend my congratulations to the organisers of the Symposium and to the publishers of the Proceedings.

Nicholas Fenn

Nicholas Fenn

Preface

Climate change is of global concern as society increases its influence on the composition of the atmosphere through, for example, the accumulation of greenhouse gases. Although uncertainty lies in the timing and scale of such changes, the potential threat to sustainable economic development is now widely recognized. Research into aspects of global warming must cover the processes that determine the physical, chemical, biological, and social factors that affect the Earth; the impacts of these changes on the environment; and the response measures that can be taken to combat undesirable changes.

Given the relevance of the subject, particularly in the context of the forthcoming United Nations Conference on Environment and Development, the British Council Division organized the Indo-British Symposium on Climate Change. This was held in Delhi from 15 to 17 January at the Taj Mahal Hotel. It was an important step in encouraging informed debate and mutual understanding, between Britain and India, in aspects of global warming.The meeting adopted the format of the Intergovernmental Panel on Climate Change and looked at the main issues, namely Science, Impacts, and Responses.

Over 250 participants attended including key policy makers, scientists, administrators, and representatives of leading NGOs (nongovernmental organizations). They were able to discuss over 30 presentations including those of Professor M G K Menon FRS, President of the International Council of Scientific Unions and Dr R K Pachauri, Director of the Tata Energy Research Institute, which tackles problems in the area of energy resources. Other speakers included Dr Ashok Khosla of Development Alternatives and Dr Anil Agarwal of Centre for Science and Environment, who represented the strong body of opinion from Indian NGOs. There were eight British speakers who represented a spectrum of views, from the official government view including those of Professor David Pearce, Special Adviser in Environmental Economics to the UK Secretary of State for Environment, through perspectives from influential scientists such as Dr Joe Farman who discovered the hole in the ozone layer, to those who reviewed the current positions of British NGOs, including Richard Sandbrook, Executive Director of the International Institute for Environment and Development and closely involved with the development of Friends of the Earth.

These proceedings are only a small contribution to the immense international efforts that are taking place prior to the Earth Summit. However it is hoped that they will contribute to this and to further collaboration between India and Britain following the negotiations on a global climate change convention. It is essential that we continue to share our views and debate our understanding of this serious issue.

We wish, on behalf of the British Council Division, to acknowledge the valuable support received from British Airways and Standard Chartered in the organization of the Symposium. The editors also wish to express their appreciation to colleagues for their unstinting support in the organization of the symposium and also their assistance in the preparation of this volume. In particular we would like to mention Leela Negi and Goodie Vohra of the British Council Division, and Amrita Achanta and T Radhakrishnan of the Tata Energy Research Institute. Sincere thanks are also due to all the speakers at the symposium whose enthusiasm and contributions made this volume a reality.

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Welcome Address

Robert Arbuthnott
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Professor Menon, Sir Nicholas, Mr Dessau, Dr Jenkins, Participants and Guests,

It is a very great pleasure for me to stand up in front of such a very distinguished gathering of scientists and environmentalists and planners and many others who are interested in this very important topic.

On behalf of the British High Commission in general and its British Council Division in particular, I would like to welcome you all today. It won't come as a surprise to those of you in the academic field to find the British Council Division organizing a seminar on the environment but some of you may wonder what it actually has to do with the cultural and educational programmes with which we are often associated, as well as of course with the enormous library network which we run in India. Actually our aim is to promote effective professional collaboration between Indian and British institutions and individuals, and in so doing about half our activities are in the area of science. In fact seven of my UK-based colleagues are scientists and so are at least as many of my senior Indian colleagues. So in discussing our programmes, as we always do with Indian colleagues and specialists, it became pretty obvious that just as in Britain the environment in general was getting nearer and nearer the top of everyone's political, industrial and other agenda, so in India it was also becoming a topic of very great concern both in the public and the private sector—hence this seminar.

We are of course already active in the environment in a number of ways as part of the Indo-British Technical Collaboration Programme in fields such as science, energy efficiency, population research, and environmental impact assessment on behalf of our Overseas Development Administration. The British here in India do have a programme of academic and research links between Indian and British universities in conjunction with the UGC (University Grants Commission), and environment is certainly one of those which gives a potential new link a good deal of priority.

A small word of information: those of you who haven't discovered it, and I think everybody has, there is a very interesting exhibition outside on books and other materials on various environmental issues and, if you want more, the World Book Fair which starts on the Pragati Maidan on Saturday, the 1st February, and lasts about nine days has an even larger exhibition of materials on the same subject on the British stand.

Now you will note from the programme that there isn't going to be a vote of thanks to the speakers today, so I'm going to do it in advance. And I would really very much like to thank not only our very distinguished speakers on the platform whom you will hear in the first session but also all the other speakers from both India and Britain, especially those who have come long distances (I don't only mean the British ones in that context) and all of you from extremely busy occupations and jobs. We are really deeply grateful to you all for sparing the time. I would also like to thank the Ministry of External Affairs and the Ministry of Environment and Forests for their collaboration, and in this connection the Honourable Minister Mr Kamal Nath will be addressing the closing session of this seminar. We are very grateful for the advice which we have received from a number of Indian scientific and other colleagues in setting up this Seminar, not least Dr Vinod Gaur, Secretary, Ocean Development, who will be with us later but has been called away to an urgent meeting—with the Prime Minister, I believe—but he is hoping to join us as soon as he can.

But above all perhaps I would like to thank my own colleagues in our Science and Technology section and indeed other parts of the British Council Division, who have toiled unremittingly to get this Seminar on the road, especially Dr Bob Frame and Dr Yaj Medury, but also many others.

In wishing you every success in your deliberations I am conscious of the fact that a seminar of this kind does not always produce a unanimity of viewpoint, but if it produces clarity about the issues and about the range of solutions, it will have achieved its purpose.

Now, may I introduce our Chief Speaker, Professor M G K Menon, who, I know, is known very well to all the Indian participants but for the benefit of the British ones, perhaps I could just say that he is currently a member of the *Rajya Sabha*; that he was Minister of State for Science and Technology; before that he was Scientific Adviser to the Prime Minister; and before that a Member of the Planning Commission. He is a very distinguished scientist himself and a Fellow of the Royal Society, and we are very honoured and delighted that he is able to come and address us today.

Global change: a viewpoint

M G K Menon
Member of Parliament (*Rajya Sabha*)
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This symposium is important because it deals with a subject that has in recent years come to occupy a position of very high priority on the agenda of governments and the media, namely the question of what is happening to the globe as we move into the future, based on our current patterns of population growth, development, and consumption.

Britain represents one of the industrialized countries of the world. India on the other hand is a developing country and is still at the stage where we will need more and more energy to produce more and more GNP (gross national product) per capita.

Britain and India have long-standing relationships, particularly in the fields of science and technology. Links with British science extend across the whole spectrum from botany to medicine and, of course, include those who were trained in Britain. Strong linkages have existed between our weather services too. The India Meteorological Department is one of the very old scientific departments and today, in the developing world, it is one of the very forward looking departments in terms of spread of observatories, the measurements that are made, the variety of parameters used, and satellite observations. The India Meteorological Department has been providing information on a synoptic nationwide or subcontinental scale and this has gone on for decades. It is therefore entirely appropriate for Britain and India to discuss the issues of climate change. But Britain as one of the industrialized developed countries of the world has been looking at these problems differently from the way we look at these problems. And the reason for it is that, for us, development is the highest priority. For India, it is a matter of lifting ourselves by our bootstraps to a wholly new level of human needs and ensuring that we can meet them. For example, in India energy consumption per capita is about 250 kg of oil equivalent. The developed world has a figure that is 20 time bigger, at about 5000 kg of oil equivalent. The United States of America has twice again the figure of the developed world in general—about 11 000 kg oil equivalent. So, when we talk of requiring

more energy, it is for primary needs of cooking, heating, industrial production —for meeting basic human needs. Energy production is therefore absolutely vital for our future.

The question of climate change has come about because we are aware that in recent past since the industrial revolution, more particularly over the period since the Second World War, there has been human activity on such a scale as to produce effects on the earth's environment which could lead to changes which, on the basis of some scenarios and models, could not only be harmful but very hazardous in the long term to human existence.

We are aware in the first instance of what we call greenhouse gases in the atmosphere. We know there is a natural greenhouse effect. And this is due to radiation trapped as a result of greenhouse gases in the atmosphere, particularly carbon dioxide, water vapour, methane, and industrial products like CFCs (chlorofluorocarbons).

Human activity is increasing the concentration of these greenhouse gases in the atmosphere. And it is scientific work which has established that this is so. Therefore we say there will be a warming due to the greenhouse effect.

The IPCC (Intergovernmental Panel on Climate Change) Report—one of the great efforts put together by an inter-governmental committee—brought together the very best scientists of the world to produce the best scientific assessment of ozone depletion. The ozone hole was discovered by the British Antarctic Survey (Dr Joe Farman) and it is interesting that this is a discovery made by scientists. Its importance lies in the fact that ozone is a protective layer which reduces the ultraviolet radiation from coming onto the earth's surface. We still have to understand what would happen if there were no ozone. We certainly know there are many things which would happen. For instance, it is known that skin cancer would increase, but it is a very complex long-term question relating to how living systems will respond. There are other features when we talk of greenhouse gases, and that's why this Symposium is important. One of the greenhouse gases is methane. Methane concentrations have been estimated essentially by extrapolations from measurements done elsewhere without taking into account what actually happens in the tropics. Methane sources are principally from rice cultivation, from paddy fields, from ruminants, from wetlands, and from mining operations. Estimates seem to indicate that the developing countries with very large paddy cultivations and large animal populations contribute significantly to methane concentrations though nowhere near to the concentration of carbon dioxide in the atmosphere. But methane is an important greenhouse gas. Indian measurements of methane carried out at the national level, involving scientific collaboration between the Council of Scientific and Industrial Research and the agricultural research system, have indicated that the IPCC estimates are high by a factor of 10. The importance of scientific work in developing countries is already

established by just this one indication.

Let me emphasize that all this is due to scientists working at a variety of places making extremely careful measurements, interacting, using these results and then finding out some of the consequences. But once the scientific data have been established, it moves into a domain involving society because it is society that is affected by climate change.

Therefore, as a consequence, one moves across from engineers to technologists to economists to social scientists. And as soon as we get into the area of impacts of responses, the human dimensions of any activity, we move away from areas familiar to scientists into areas involving society. The UNCED (United Nations Conference on Environment and Development) will discuss all these issues. The International Council of Scientific Unions acting as Principal Scientific Adviser to UNCED brought together not only natural scientists, but also large numbers of social scientists and associated organizations such as the International Social Science Council, the International Institute for Applied Systems Analysis in Vienna, the European Science Foundation, and so on, at the Vienna meeting in November 1991 to discuss global change and the reasons for it.

I also want to mention that climate change is one facet of global change. We have to recognize that global change relates to the earth's environment as a whole. And there are many things which human society is doing to this earth's environment other than putting carbon dioxide or methane or CFCs into the atmosphere. For example, there is a whole area relating to bio-diversity and the manner in which this enormously rich natural resource is gradually getting extinct due to human activities. It is therefore important that we have to act in unison globally. We have to find ways where we function on the basis of solidarity as human society in dealing with these questions.

Today if one looks at the picture starting from climate change, it is clear that the largest part of greenhouse gas additions to the earth's atmosphere is due to the industrialized developed countries of the world. It is also true because the developing world has had such low per capita energy consumption that, even when multiplied by the large population, its contribution to the principal greenhouse gas (CO_2) has been very small—a ratio of 70:30 between the developed and the developing countries. And this continues to be the case. However, it is also true that the developing countries have today a very high population growth rate. We are talking of a population around 5.7 billion by the turn of the century. Our demographic projections will take us anywhere between 8 and 15 billion depending on how one slows it down. And this country itself is an example where we have a total fertility rate of over 4 (4.3 or thereabouts) compared to the 2.1 required for stabilization. We have an annual population growth of over 2%, which is about 17 million a year. So the populations in the developing world are growing and with it their needs,

particularly energy needs. Therefore, as we move into the future, the anthropogenic effects produced by the developing countries will start becoming important and of great significance from the viewpoint of global change. And we certainly would like to ensure that this does not happen by ensuring that this population growth does not take place on the scale predicted. But one can almost assert today that whatever one does, unless there is education on a universal basis at the elementary level, particularly of women, and a degree of female economic independence, this will not come about. Populations will continue to grow. Therefore, it is in the global interest of the developed and developing countries to ensure that development does take place in the developing countries.

The last point that I would like to make is that in all of these areas, whether it relates to the primary work on greenhouse gases, atmosphere, the oceans, various observing systems or making an analysis downstream which involves modelling, a great deal of laboratory work as well as modelling which enables us to predict is called for. That is the whole basis for the International Geosphere Biosphere Programme which was launched, a global programme of the World Climate Research Programme, by the World Meteorological Organization and the International Council of Scientific Unions along with the International Ozone Commission and the International Oceanographic Commission. So I would say that support for research for these studies and analysis is fundamental. The costs are small but they will tell us what is the nature of the environment in which we live; what is the nature of its response to what we are doing to it; and how we need to respond, to adapt, and to modify our pathways in development to make sure that life is sustainable in the long term.

Thank you very much.

Inaugural Address

Nicholas Fenn
British High Commission
Chanakyapuri
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'It is for me an honour to welcome you to this symposium on climate change. I do so as a three-fold impostor:

- First, it is a monstrous impertinence for a High Commissioner of eight weeks' standing to inaugurate anything in India.
- Second, I come to this conference while my Foreign Minister is actually in the air on his way to Delhi. What would Douglas Hurd say if he knew I was discussing the weather when I should be preparing for his arrival? In these circumstances I hope you will forgive me if I do not stay throughout the conference.
- Third, I am a mere layman among experts. This is a familiar experience. At our most expert embassy in the world—Peking—I was the only non-sinologist among the senior staff. My ambassador used to say that my job was to remind him that the rest of the world existed.

My own academic qualifications are in medieval history. It was therefore natural that I was in due course appointed Assistant Director of Science and Technology in the FCO (Foreign and Commonwealth Office) in London, in succession to a nuclear physicist. There had to be a change of style.

Timely symposium

I once attended a lecture which began: 'If all the experts in the world were placed end to end, that would be a very good thing'. I hasten to say that I was not the lecturer. If experts sometimes need laymen to re-establish the context of their work, there can be no doubt that laymen need experts to probe beneath the conventional surface of things. Perhaps the distinction is a false one. After all, an expert is only a layman who knows what he is doing. Be that as it may, India and Britain are fortunate to have so many eminent experts on the subject of climate change. If I

may say so, it stands greatly to the credit of the British Council that they have brought so many of them together for the symposium. Not for the first time, we are in their debt.

The symposium is very *timely*. First, because of the approach to the UNCED (United Nations Conference on Environment and Development) in Brazil in June. Never before will so many heads of state and government ministers, experts, and voluntary organizations have gathered together. We want practical results from that meeting, in the form of conventions on climate change and other crucial environmental issues such as bio-diversity. There is much still to do to prepare for UNCED. Part of that, of course, must be detailed negotiation and examination of fine print, which is mainly the task of government experts. But there is also a real need for informed and open debate between scientists, economists, politicians, and others on the extent of the real environmental problems, and possible solutions and their costs. We have not brought British experts here to negotiate, still less to preach; but to share their expertise and wisdom with each other and with a wide range of eminent Indian experts assembled here. I hope the result will be a step towards consensus. In matters of environment, consensus, like time, is a necessary and scarce commodity.

Secondly, the symposium forms part of a bilateral relationship.

It is important also to see this conference in the overall context of the extensive collaboration between Britain and India on the environment in general. Co-operative projects and programmes deal with a whole range of environment-related topics —from agriculture and forestry, through environment impact assessment of industrial projects, to CFCs (chlorofluorocarbons) and assistance with energy efficiency measures and population studies. At presents, 40 million pounds are available for environmental forestry under the British Aid Programme and a further 50 million pounds for energy efficiency.

Process must continue

Less formal activities also take place through a wide range of contacts—from charities to companies, from individuals to large industrial concerns. Collectively I believe they make a major contribution to safeguarding the environment of both India and the world. This process must continue.

The conference is timely for a third reason: the acknowledged crisis in which we stand.

It is now agreed internationally that human activities are altering the natural balance of our planet. There are many factors at work—increased emissions due to industrialization, the loss of forests to absorb the ever increasing quantities of carbon dioxide in the atmosphere, and not least the rapidly expanding population of the world and its ever increasing consumption of scarce resources. Given the

complex nature of the problem it is difficult to predict such changes with great accuracy. Climate change is probably the most difficult area of all.

However the IPCC (Intergovernmental Panel on Climate Change) estimate that an increase of 0.3 °C per decade is the most likely outcome. It is, they say, their 'best estimate'—a statement which indicates, at least to a layman, that this really is rather a tricky question, about which the experts know only a little more than the rest of us. An American poet once defined research in these terms:

> Blind men, lost in a maze, feel the walls to find
> That each seductive alley in its turn is blind.
> Their pilgrimage by each new failure redefined
> Mock not: their sightless fingers trace the future of mankind.

What, some might say, is 0.3 °C per decade between friends? We would find the damp London winter a little less chill; and the summer heat of Delhi is already so scorching that it will feel only a little bit worse. But the impact goes well beyond this. Sea levels will change. Countries will change shape; some may even disappear. That will bring population movements. A warmer earth will make growing food easier in some places, but more difficult in others. And these changes once made may well be irreversible. There can rarely have been a bigger challenge to scientists and policy makers. Yes, Gentlemen, it seems to the layman that these tentative figures matter very much indeed.

Three Working Groups

In 1988, the IPCC was set up to report on global warming as a basis for international co-operation. It comprises three Working Groups, namely Science, Impact and Responses. The Science Group, which has brought together over 300 scientists is chaired by the UK and its work will be reviewed in the Science Session later this morning by Geoff Jenkins of the Met Office. He will also review the work of IPCC as a whole later in this session.

The structure of IPCC has been followed in this symposium. This is because it is essential to see all the aspects of climate change together. The spectrum of debate stretches from the rigours of accumulating the scientific data in order to increase our understanding through the social and developmental aspects of the impact of these changes to the political and philosophical shifts in attitude which are required to respond to such changes.

Science

At the governmental level we are most interested in scientific research into topics such as the atmosphere and the oceans. This is an area of particular interest in the UK. There is a long tradition in these areas as indicated in the first session when

Joe Farman—who first discovered the hole in the ozone layer—will look at the latest assessment of the changes taking place in the atmosphere; and also David Pugh will look at the role of the oceans in the process. We will be joined by representatives from DST (Department of Science and Technology), CSIR (Council of Scientific and Industrial Research) and the Department of Ocean Development, notably Professor Vinod Gaur, who has been so generous in his assistance to the symposium organizers. Together then with our colleagues from the Indian scientific community we will be brought up to date in our understanding of these complex issues.

Impact

The impact of climate change is where scientists' predictions impinge on our futures as I mentioned earlier. Predictable weather patterns and sea level are essential for our well-being. And there are many factors which aid and abet climate change. As Professor Conway of Imperial College and the Ford Foundation will describe in his presentation, agriculture is both culprit and victim. We also have to examine carefully the many sources and sinks for the greenhouse gases. These are complex issues and their implications need to be fully reviewed by those such as Dr Tewari. In Britain we are devoting a lot of resources to look at them, and this includes the Climate Research Unit at the University of East Anglia whose work will also be discussed tomorrow.

The impact of climate change will affect the rural areas and these are obviously a major area of concern to India. The urban and industrial sectors also play a key role of course. With increasing industrialization there will be an associated rise in energy demand and with it, an increase in supply. This is an irreversible trend; only the rate of change can be influenced. That has to be a conscious decision—and one which needs careful thought. We are very fortunate to have Jim Skea from the Science Policy Research Unit at Sussex to discuss these problems. I am also very pleased to see a contribution from Dr Pachauri of the Tata Energy Research Institute whose work in this area is well known.

Responses

Our deliberations on the origin and impact of climate change are only part of the equation: we have a collective duty to consider our response. You will have this opportunity on Friday, in what promises to be a most stimulating session. Following presentations on our respective governmental activities to date I am very pleased to see David Pearce, who is the Special Adviser to the UK Secretary of State for the Environment in environmental economics—a new subject which is central to the decision-making process regarding effective policies to deal with these issues. This is a particularly daunting task at the global level. It is said that he was partly responsible for bringing Green politics to the fore in the present government. For

that he deserves our gratitude. The subject has moved firmly into the main political agenda after a long time in the wings. Our government has published a White Paper on the Environment called 'This Common Inheritance'. I think that phrase is appropriate here today in India, as it is anywhere in the world at this time.

But it is important that we also look at matters through less official eyes—we will hear comments from those representing the non-governmental organizations in both countries and who are actively involved in the environment from a variety of viewpoints. These include Jim Skea and Richard Sandbrook, who have had a long involvement with these issues. The media will also be represented and Mark Tully needs no introduction to anyone who knows the BBC in India. We will also have papers from Anil Agarwal of the Centre of Science and Environment, and from Ashok Khosla of Development Alternatives, who represent the large informed body of non-government organizations who play such an important role in the whole debate. We will also hear about the activities of their British counterparts before we hear about the various formal and legal structures that are coming into being as a response at the national and international level. In particular it will be interesting to hear from Professor Rahmatullah Khan of JNU (Jawaharlal Nehru University), who is India's first Professor of Environmental Law.

Ladies and Gentlemen, we have a wide range of speakers across many disciplines, covering many angles of this crucial subject. I extend my warmest thanks to each and every one of them—whether I have had time to mention them or not. I do not doubt that we shall leave this symposium with a greater understanding of the issues, their importance, what can be done about them, and at what cost and to whom. It gives me great satisfaction to be present at this inaugural session.

I end, as I began, by paying a layman's tribute to the men of knowledge and experience and wisdom who will lead your debates. My interest in the future is like that of Charles Kettering: I am going to spend the rest of my life in it. So are our children. As an historian, I am quick to acknowledge our debt to the past. Isaac Newton attributed his vision to the fact that he stood on great men's shoulders. What is distinctive about the closing decade of our century is that what we do today will affect not just the quality of life in the future but the probability of life at all on this planet. It was John Buchan who asked us to pay our debt to the past by putting the future in debt to us. That is the challenge before us. Gentlemen, I have no doubt that you will put us in your debt. I am proud to inaugurate your conference.'

U N C E D: an overview

Erling Dessau
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Professor M G K Menon, Sir Nicholas Fenn, Dr Geoff Jenkins, distinguished Delegates, Ladies and Gentlemen,

We are at a critical juncture of human history, for never before did the concerns of the immediate future cast such gloom on the thinking of the present. The portents are so ominous and imminent that to wait further till every scientific observation could be explained with absolute certainty would be more than unwise. Whether the causal relationships have been understood clearly or not, global climate change, essentially resulting from man-made activity, has obviously started manifesting itself. It appears that, according to available data, six of the eight warmest years on record have been in the 1980s with 1990 as the hottest year. The report of the IPCC (Intergovernmental Panel on Climate Change) depicts a scenario that is truly disturbing. Various independent analyses show that global temperatures in the eighties were higher than in any other decade before. If the rate of accumulation of greenhouse gases in the atmosphere is not reduced, by the middle of the next century the quantum would be double that of the pre-industrial age. It is feared that the warming trend would soon accelerate to between 0.3 and 0.4 °C per decade, even taking into consideration the beneficial effects of the oceans.

The implications of this change on life-systems are likely to be enormous. With its effect on the planet's snow and ice cover, marked retreat of the mountain glaciers, large-scale evaporation of water and increase in cloudiness, water supplies are going to be less reliable, and droughts and cyclones will hit with greater intensity and periodicity. The rise in water level would not only inundate low-lying areas, its effect on inland rivers and lands would be disastrous for agriculture and aquaculture as well. According to IPCC estimates, about 300 million people would be severely affected by a one-metre rise in the sea level. Hundreds of millions of people will be rendered environmental refugees.

It is in this context that the UNCED (United Nations Conference on

Environment and Development), also referred to as the Earth Summit, and the preparatory process leading to the Summit, including this symposium, assume such crucial significance. The Conference, scheduled to be held in June in Rio de Janeiro, will try to design integrated strategies to prevent further degradation of the environment and foster sustainable development. Both environmental protection and sustainable development require prudent management of natural resources. Much of today's crisis is due to unsustainable consumption patterns with little respect for the earth's carrying capacity. In view of this, UNCED ai]s to chart out a philosophy as well as an action plan for the future, including the immediate future. UNCED would take stock of history, so that we know what to do to ensure that history does not repeat itself.

This obviously calls for a global effort and will the like of which have not been marshalled before. During the last two years, the preparations have been mounting. Governments, non-governmental organizations, private industries, scientific and technical bodies, United Nations and other international agencies, trade unions, religious groups—virtually every cross-section of interests and groups, all over the world—have been engaged in articulating their perceptions on the Agenda of UNCED. Never before have so many strands of opinion from so many sources converged to the goal set for the Summit. While the Summit is expected to be attended by the heads of state or government of about 150 nations, the churning process has been no less important.

The countries are preparing their national reports; in fact, 73 countries have already submitted theirs. Three Preparatory Committee meetings have already been held, and the fourth and final meeting is scheduled to begin in early March in New York. Based on the recommendations of the Preparatory Committee and its working groups, UNCED is expected to act on an *Earth Charter* which is a declaration of basic principles for the conduct of peoples and nations 'to ensure the future viability and integrity of the Earth as a hospitable home for human and other forms of life'. Equally important, and operationally perhaps more significant, would be an Agenda for Action, entitled *Agenda 21,* to establish an agreed action-programme for the next century for the issues to be addressed by the Conference, focusing on the priorities, targets, cost estimates, modalities, and arrangement of responsibilities. Participants would naturally be required to explore the options for new and additional financial resources, technology-transfer as well as strengthening of institutional capacities and processes.

Besides the *Earth Charter* and *Agenda 21*, the Earth Summit is expected to produce agreement on legal measures such as conventions for the protection of the atmosphere, bio-diversity and also perhaps on forests. UNCED would thus mobilize world opinion to provide the basis of a set of emerging priorities that would include strengthening of developing economies, reversing the outflow of resources from

developing countries and ensuring their access to new and additional resources and environment-friendly technologies, eradication of poverty, reversing the destruction of natural and genetic resources, changing the patterns of production and consumption that are unsustainable, ensuring food security, availability and protection of water supplies, and also ensuring energy supplies and industrial production that would restrict GHGs (greenhouse gases) emissions.

As the UNCED Secretary-General Mr Maurice Strong, who visited India last month, commented, 'the Conference offers a unique opportunity to provide the basis for the major shift in inertia required to put us on the pathway to a more secure and sustainable future. At the core of this shift there will be changes in our economic life, a more careful and more caring use of the earth's resources and greater co-operation and equity in sharing the benefits as well as the risks of our technological civilization. The Conference must provide a new basis for relations between North, South, East, and West: a new global partnership based on common interest, mutual need and shared responsibility, including a concerted attack on poverty as a central priority for the 21st century. This is now as imperative in terms of our global environmental security as it is in moral and humanitarian terms. The primary responsibility for our common future on this "*Only One Earth*" is in a very real sense "in our hands".'

So much is thus at stake. It is, therefore, most opportune that the British Council Division of the British High Commission has taken the initiative to invite the foremost scientists, policy makers, and grassroot activists from Britain and India to debate and encourage mutual understanding on climate change which is going to be a key thrust area in UNCED. UNDP (United Nations Development Programme) has been deeply involved in these activities and has undertaken a series of measures with a view to be a rallying point in this regard. You must also be aware of the billion-dollar-plus fund, called the Global Environmental Facility, established to encourage and fund pilot projects in the areas of preserving bio-diversity, protection of the ozone layer, reduction of pollution of international waters and, importantly, limiting emissions GHGs—all of which are vitally linked with climate change. UNDP has in fact suggested a regional and a country project for India to study and help arrive at a strategy for reduction of GHGs.

An integrated strategy is imperative since the issues are not only scientific and technological, where also debate continues about scientific certainty, but are also related to broader questions of equity. As is generally understood, sustainability cannot be achieved without equity. We also know that neither pure market-mechanisms nor heavily centralized planning necessarily spawn environmental protection. Besides, the scientific questions are also inter-connected. For example, tropical forests, considered to be distributing heat away from the equator, seem to influence the global climate significantly. India, evidently, has a key role to play in

providing leadership to many developing countries in this respect.

Of the many significant initiatives taken in the last three years, we are aware of the important work done by UNEP (United Nations Environment Programme), the IPCC (Intergovernmental Panel on Climate Change), WMO (World Meteorological Organization), ICSU (International Council of Scientific Unions), the Toronto Conference on the Changing Atmosphere, the Hague Conference, the G-7 Summit of 1989, the Noordwijk Ministerial Conference on Atmospheric Pollution and Climate Change, the Bergen Ministerial Declaration and the like. In India also, we witnessed a number of organizations and experts, both within the Government and outside, engaging themselves in a major way to grapple with this complex issue. Global warming is indeed being taken in responsible quarters as a *Global Warning.*

As the representative of the UNCED Secretary-General in India, I, therefore, trust this symposium will be a landmark on the road to Rio and its proceedings be striking enough to influence global thinking on the subject.

Thank you.

The Intergovernmental Panel on Climate Change: an overview

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I would first like to pass on apologies from Sir John Houghton, the Chairman of IPCC (Intergovernmental Panel on Climate Change) Working Group 1, who has been prevented by another IPCC meeting in China from participating in this symposium. I thank the British Council for inviting me to speak in his stead.

To find the real starting point for IPCC we have to go back well over a hundred years ago, when Tyndall realized that carbon dioxide and water vapour could absorb infrared radiation and thereby stop some of the heat leaving the earth/atmosphere system. Thus the natural greenhouse effect was discovered, although it was not given the name until some time after. Nearly hundred years ago Arrhenius postulated that CO_2 in the atmosphere was rising due to fossil fuel emissions, and that if its concentrations doubled, the earth could become 5 °C warmer. In the 1930s Callander hypothesized that the rise in global temperatures over the previous decades was due to increasing CO_2.

In 1957 the first accurate global measurements of CO_2 were began by Keeling, and it is this record which has shown the rapid rise in CO_2 concentrations over the past three or four decades. In the mid-seventies the first credible global climate predictions using large computer models were published in the US, and at about the same time Ramanathan and others drew attention to the fact that CO_2 was not the only greenhouse gas being increased by human activity; others, notably CFCs (chlorofluorocarbons), were very significant contributors.

It is therefore sometimes surprising to scientists when they see the man-made greenhouse effect and the potential for climate change presented in the press as if it were something new, when the basic principle has been known since the last century. Nevertheless it remains true that, despite the staggering amount of research that has been undertaken since then, and the huge increases in our understanding that this research has brought about, we still cannot predict climate change with great accuracy and we know very little about its regional patterns.

The recent events that lead up to the formation of IPCC started with the First World Climate Conference in 1979, and the UNEP (United Nations Environment Programme)/WMO (World Meteorological Organization)/ICSU (International Council of Scientific Unions) meeting at Villach in Austria in 1985. The activity over the ozone layer and the threat to it from CFCs, and in particular the discovery of the ozone hole by Joe Farman, although not directly relevant to climate change, greatly heightened public and governmental awareness of the potential of relatively small changes in atmospheric composition (a few hundred parts per trillion) to have devastating influences on the natural state of our planet. The Vienna Convention for the Protection of the Ozone Layer soon led to the Montreal Protocol to regulate CFCs. It should be noted that these regulations were agreed in advance of observational evidence of the damage to the ozone layer by CFCs; this later evidence has since led to a strengthening of the Protocol, and it is being reviewed again in 1992.

Following its success in establishing the Montreal Protocol, UNEP turned its attention to global climate by setting up jointly with WMO the Intergovernmental Panel on Climate Change in November 1988. Recognizing that, sooner or later, discussions would begin on the need for, and form of, any regulations to protect global climate, it wisely decided that these discussions should be well informed from the outset. The purpose of IPCC was, and remains, to provide timely assessments in all areas which might have an impact on policy formulation.

IPCC then commissioned three Working Groups and entrusted them with the preparations of assessments in the areas of scientific understanding of climate change, the effects and impacts of climate change, and the formulation of possible response strategies. It also established a special committee to facilitate the participation of developing countries in these assessments. The three Working Groups met in January 1989 and set a very strict timetable for the preparation of the first reports. The Working Groups duly completed their reports by mid-1990, and these were brought together in the First Assessment Report in August 1990.

Following this, the Second World Climate Conference brought an unprecedented number of world leaders together in November 1990 in Geneva to set up their stalls. And in December of that year the United Nations General Assembly adopted Resolution 45/212 on the need for discussions toward a Framework Convention on Climate Change. The resolution created the Intergovernmental Negotiating Committee for this purpose, and also asked IPCC to continue providing up-to-date assessments. The update of the IPCC assessments is now under way, and will be presented in April this year, just before the major United Nations Conference on Environment and Development in Rio de Janeiro in June, which Mr Dessau has already spoken about in detail.

In this overview I will say little of the detailed results from the first IPCC

assessments, but I will say something about the process itself. The three Working Groups covered the following areas: science, impacts and policy responses. In each case, as I have noted, individual experts were asked to take the leading role in preparing drafts, which were then modified and finally accepted by the full Working Group.

Each of the working groups chose somewhat different mechanisms to prepare the assessments, so I will concentrate on the mechanism used by Working Group 1. The first Working Group meeting selected a number of experts (about thirty in all), on the basis of their known expertise, to act as the lead authors of the assessment. These authors then invited a larger number of people to join them in preparing drafts through the mechanism of international workshops. The drafts were sent out for peer review at two, or sometimes three, stages and were extensively re-drafted to produce the final version. The Working Groups were also asked to prepare summaries of the Report specifically to meet the needs of policy-makers who are often not well versed in the science or economics, for example. These Policymakers' Summaries were drafted by the same group of lead authors, subjected to the same stringent peer review as the main report, and then agreed at the final meeting of the Working Group. The IPCC report and their Policymakers' Summaries are therefore the product of a great number of experts, and have been internationally accepted.

The updating of the IPCC assessments is already well under way; indeed the final workshop of the Science Assessment is being chaired by Sir John Houghton as we speak. Early indications are that the climate predictions are not substantially altered, but there have been some changes in our best estimates in other areas, although impact on policy is likely to be great.

In conclusion, I think it is fair to say that, despite its limitations (and one of these was the failure to involve more developing country scientists, which has been rectified to a certain extent in the preparation of the assessment updates) the IPCC process has been successful in its stated aim of providing comprehensive, state-of-the-art, internationally accepted assessments which have allowed, and will continue to allow, negotiations to be based on a firm foundation. Credit for this must go to the IPCC Chairman, Professor Bert Bolin, to the three Working Group chairmen, and to the literally hundreds of scientists from tens of countries who gave freely of their time and expertise in order to undertake this vital task.

The effect of ozone depletion on climate

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In the last thirty years the rapid increase in the consumption of fossil fuels and the rapid expansion of industrial and domestic markets for halocarbons have drastically altered the atmospheric concentrations of numerous trace gases, to the extent that the world is now faced with some very serious problems. On regional scales, rain is being acidified, and air quality in the boundary layer as indicated by the rising concentrations of oxides of nitrogen and of sulphur, of hydrocarbons and in spring and summer, of ozone, is being severely degraded. On a global scale the stratospheric ozone layer is being depleted, and there is growing concern over the speed at which climate change is being forced.

The most dramatic effect has been the very severe depletion of the ozone layer over Antarctica each austral spring. The total ozone column is reduced by more than 50%; in a layer about 12 km thick, centered at about 17 km altitude, the destruction exceeds 95%. There is now general agreement that this depletion, usually referred to as the 'ozone hole', has been caused by the accumulation in the lower atmosphere of several halocarbons, most notably methyl chloroform and the long-lived CFCs (chlorofluorocarbons) and halons. The chlorine loading of the stratosphere is now more than six times the natural loading, and the bromine loading has increased by about 50%.

In the Northern Hemisphere the decrease in column ozone is less dramatic, but is more widespread. There is the same variation with season as in Antarctica. The loss since 1969 is about 12% in spring and early summer in mid-latitudes. The rate of loss has increased in the last decade, and there is little doubt that this is linked with the increase in chlorine and bromine loading.

The depletion of stratospheric ozone leads to an increase in the solar ultraviolet radiation reaching the surface of the earth. Ultraviolet radiation can harm many living organisms, including man, and has adverse effects on some materials. This has caused much concern, and many countries have decided to phase out the production of

CFCs, halons and other halocarbons, under the terms agreed in the Montreal Protocol.

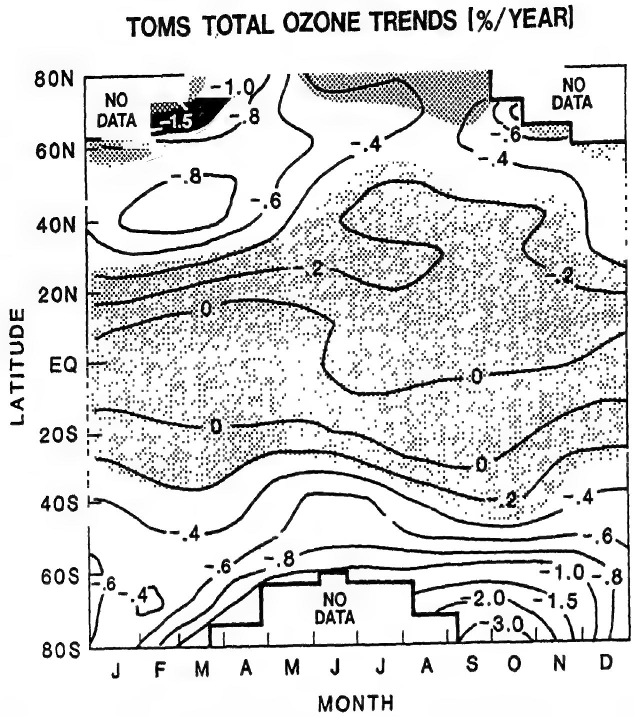
Ozone also absorbs visible solar radiation, and absorbs and emits infrared radiation. When the concentration of ozone is changed at altitudes about 30 km, is is the change in the absorption of solar radiation that dominates the effect on the troposphere/surface climate system. A decrease in ozone forces a warmer climate. When the change in ozone occurs at lower altitudes, it is the change in the interaction with infrared radiation that has greater effect, and a decrease in ozone forces a cooler climate. The magnitude of the cooling depends strongly on the altitude at which the change in ozone occurs. A change in the upper troposphere has the greatest effect; changes below 5 km and above 20 km have only small effects.

Man's activities are, in fact, changing to distribution of ozone in two quite distinct ways. The concentration of ozone is being diminished in the stratosphere and increased in the troposphere. There are therefore opposing effects on climate, the depletion of ozone in the lower stratosphere forcing cooling and the depletion of ozone in the upper stratosphere, together with the increase of ozone in the troposphere, forcing warming. Some workers have estimated that the resultant effect over the last decade has been to produce a cooling comparable to the heating forced by the direct radiative effects of the CFCs. However, much more needs to be known about the changes in the vertical profile of ozone before this estimate can be accepted.

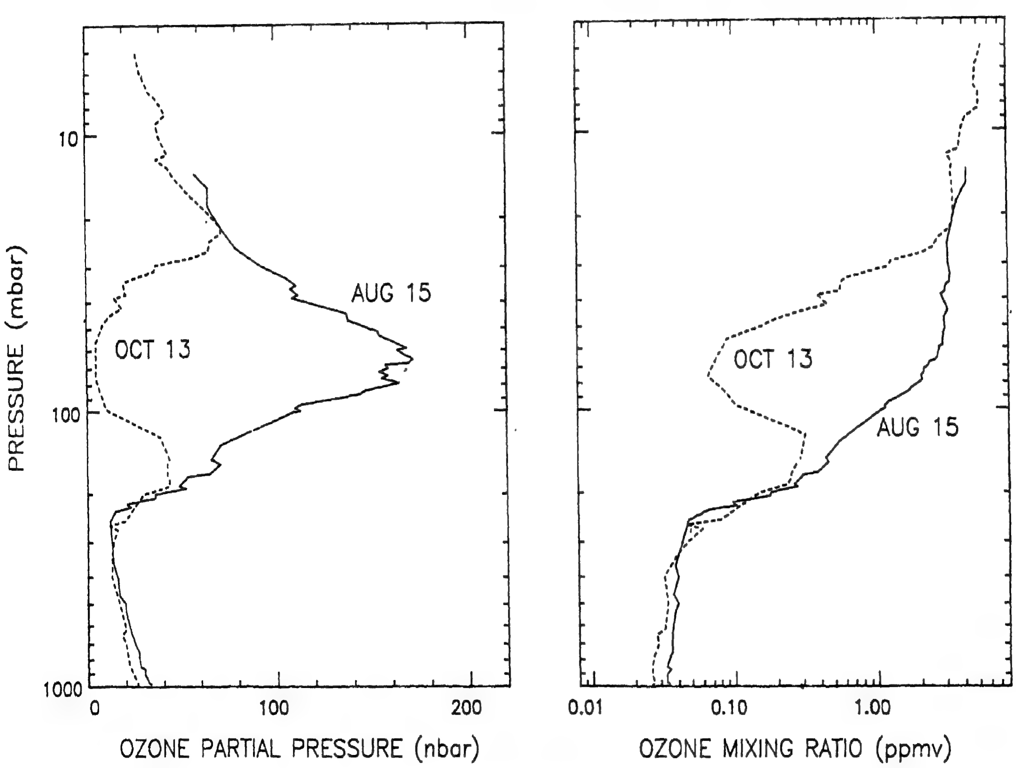
Much less is known about the possible indirect effects of changes in ozone. There is concern that damage to the biosphere, caused by ultraviolet radiation, could reduce the uptake of carbon dioxide by vegetation, and by the phytoplankton in the oceans, and so increase the rate of accumulation of carbon dioxide in the atmosphere. Whilst this is speculative, it does show that it would be imprudent to condone further depletion of the ozone layer as a possible antidote to global warming. The aim must be to solve both problems, rather than to trade one off against the other.

Editors' note

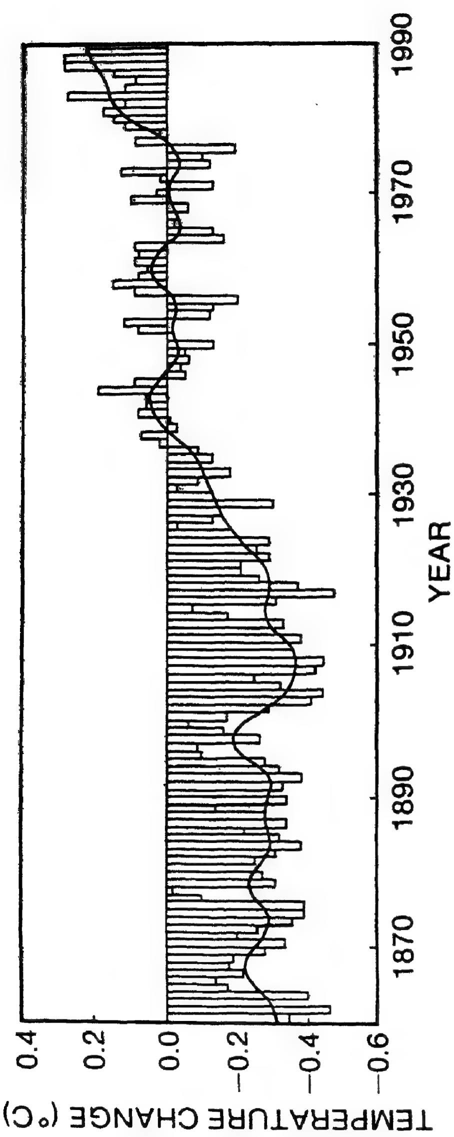
To supplement the text of the hand-out distributed by the author at the conference, he has also sent a set of figures. These are reproduced as part of the paper on the following pages.

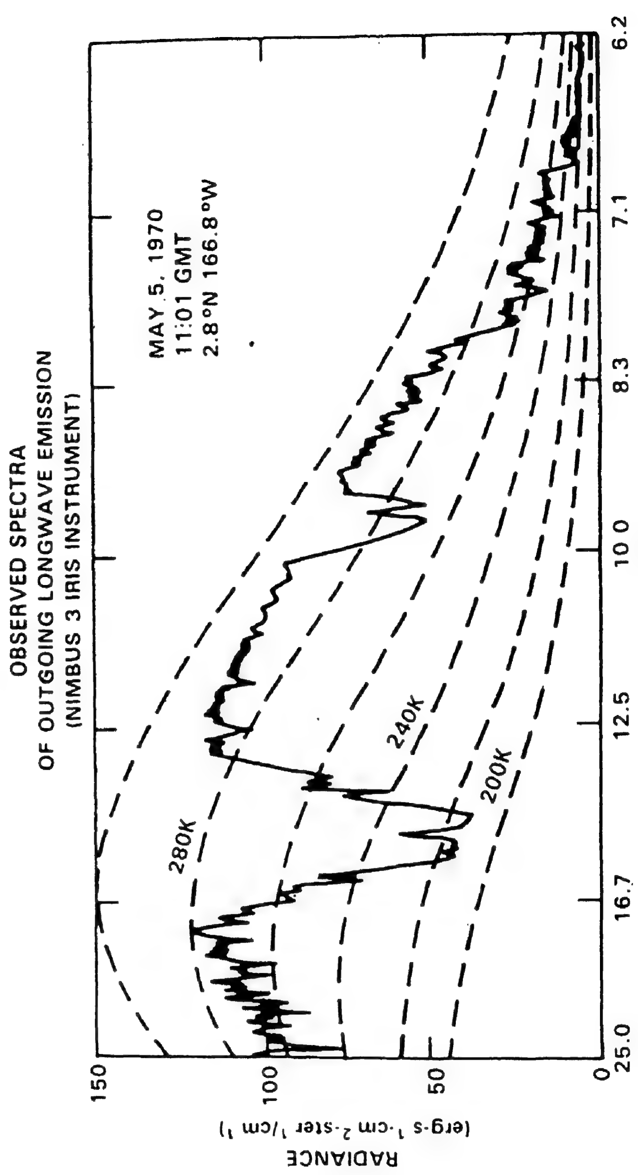


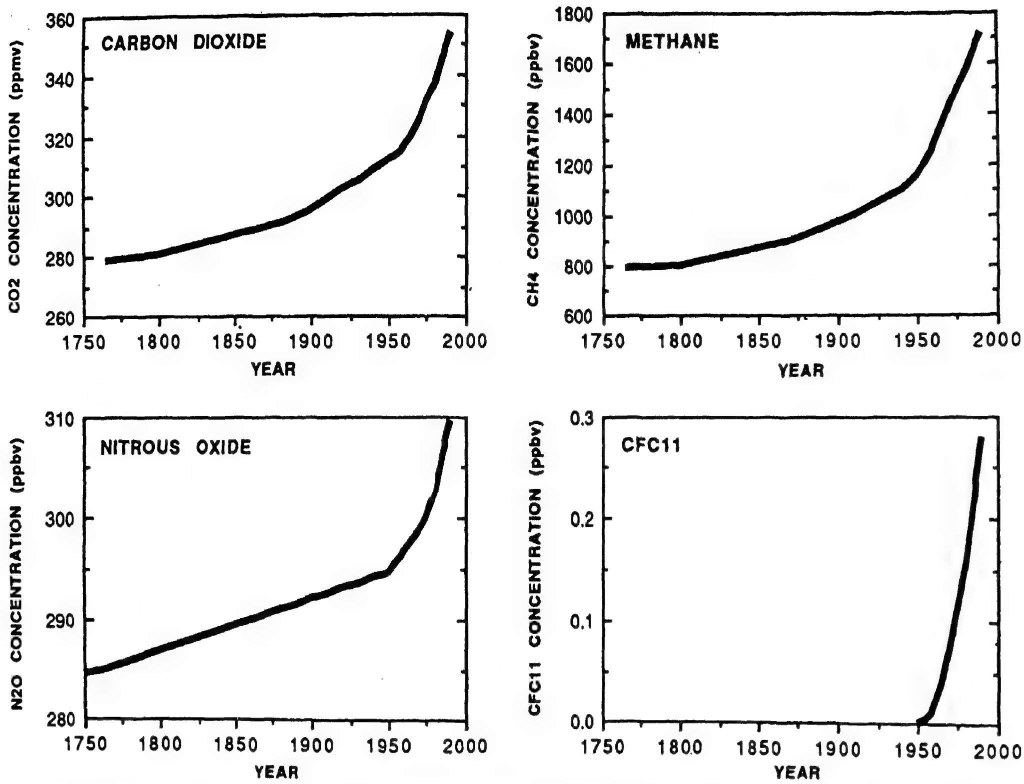
Trend of monthly total ozone across latitudes (%/year) according to TOMS satellite imagery.



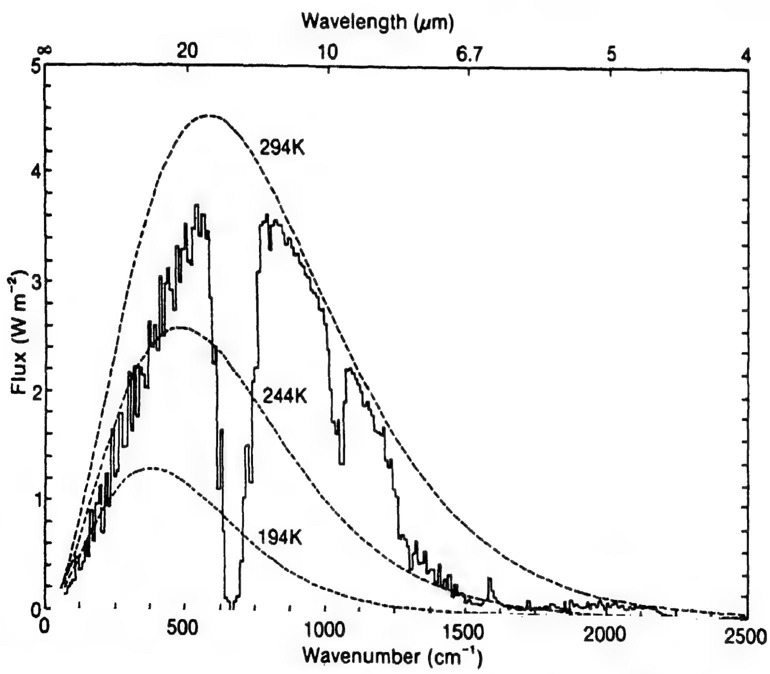
Depletion of ozone layer and distribution of ozone mixing ratio over the Antarctica for 15 August and 13 October.


TEMPERATURE CHANGE (°C)
0.4
0.2
0.0
−0.2
−0.4
−0.6
1870
1890
1910
1930
1950
1970
1990
YEAR

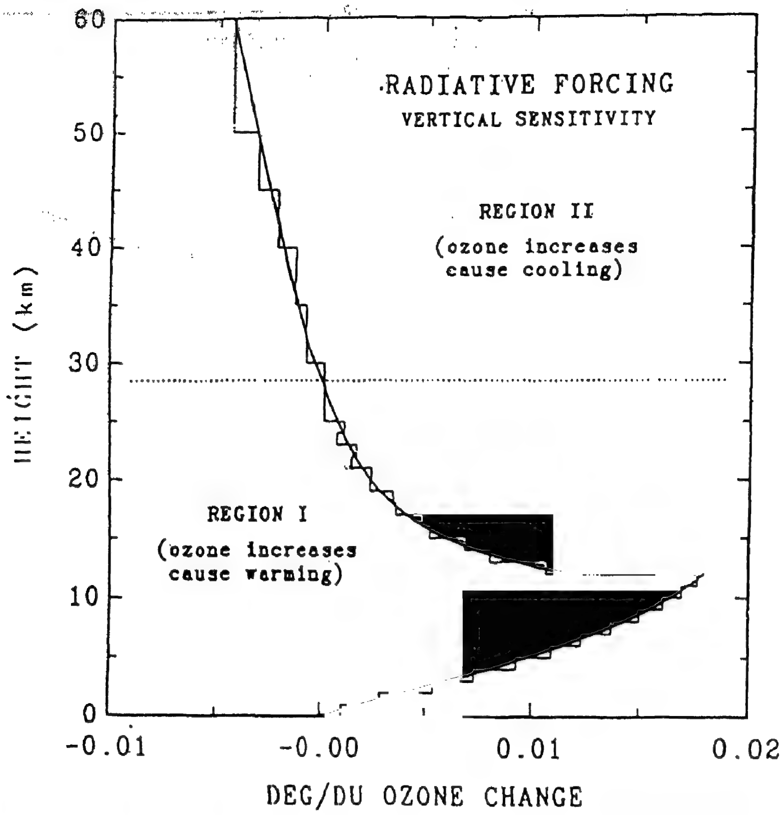

OBSERVED SPECTRA
OF OUTGOING LONGWAVE EMISSION
(NIMBUS 3 IRIS INSTRUMENT)
MAY 5, 1970
11:01 GMT
2.8°N 166.8°W
280K
240K
200K
RADIANCE
(erg-s-1-cm-2-ster-1/cm-1)
150
100
50
0
25.0
16.7
12.5
10.0
8.3
7.1
6.2
WAVELENGTH (μm)



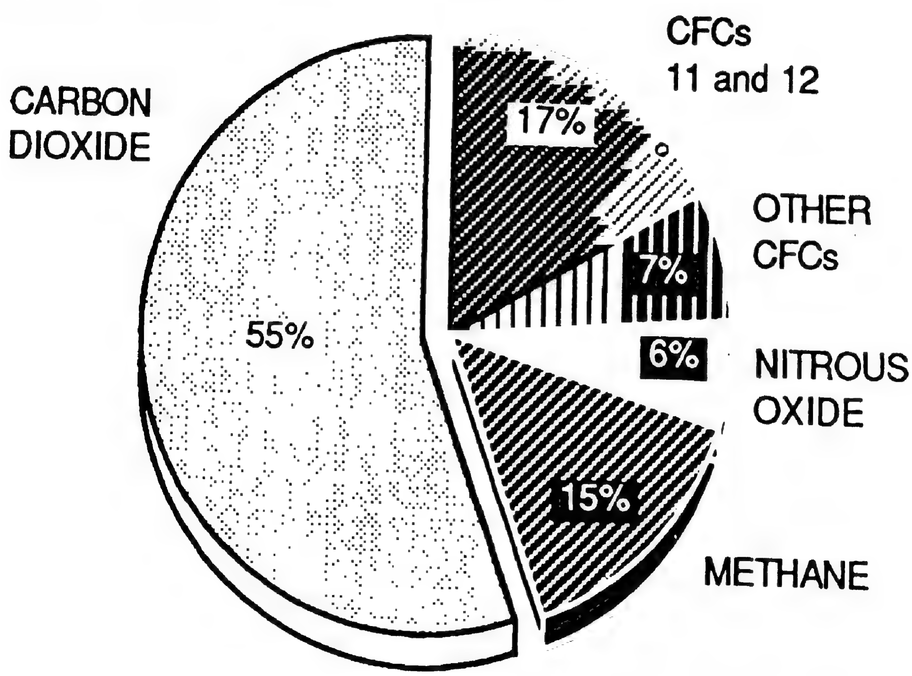
Concentrations of carbon dioxide and methane, after remaining relatively constant up to the 18th century, have risen sharply since then due to man's activities. Concentrations of nitrous oxide have increased since the mid-18th century, especially in the last few decades. CFCs (chlorofluorocarbons) were not present in the atmosphere before the 1930s.



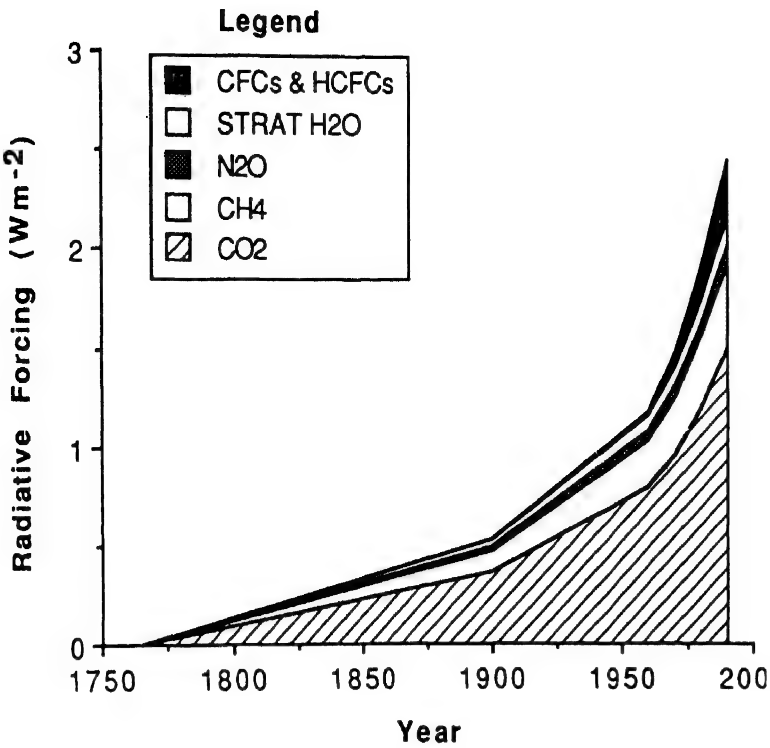
The dashed lines show the emission from a black body (Wm^{-2} per $10cm^{-1}$ spectral interval) across the thermal infrared from temperatures of 294K, 244K, and 194K. The solid line shows the net flux at the tropopause (Wm^{-2}) in each $10\ cm^{-1}$ interval, using a standard narrow-band radiation scheme and a clear-sky mid-latitude summer atmosphere with a surface temperature of 294K (Shine, personal communication). In general, the closer this line is to the dashed for 294K, the more transparent the atmosphere.



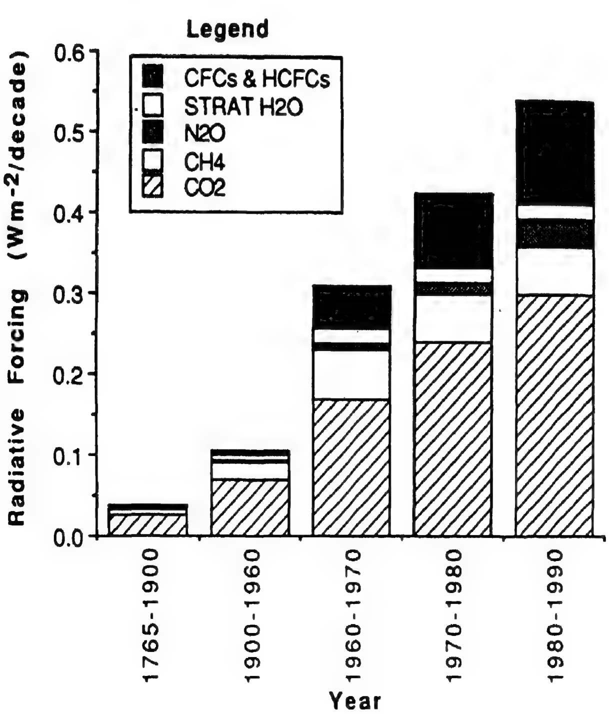
Radiative forcing sensitivity of global surface temperature to changes in vertical ozone distribution. The heavy solid line is a least squares fit to one-dimensional model radiative-convective equilibrium results computed for 10 Dobson unit ozone increments added to each atmospheric layer. Ozone increases in region I (below ~30km) and ozone decreases in region II (above ~30km) warm the surface temperature. No feedback effects are included in the radiative forcing.



The contribution from each of the human-made greenhouse gases to the change in radiative forcing from 1980 to 1990. The contribution from ozone may also be significant, but cannot be quantified at present.



Changes in radiative forcing (Wm^{-2}) due to increases in greenhouse gas concentrations between 1765 and 1990. Values are changes in forcing from 1765 concentrations.



Decadal contributions to radiative forcing (Wm^{-2}) due to increases in greenhouse gas concentrations for periods between 1765 and 1990. The changes for the periods 1765-1990 and 1900-1960 are the total changes during these periods divided by the number of decades.

Indo-British Symposium on Climate Change, 15-17 January 1992, New Delhi

Application of mathematical modelling for prediction of climate change

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Introduction

It is both a pleasure and an honour for me to give a lecture at this symposium. Since the scope of the symposium ranges from issues of scientific nature to matters of social response, I have decided to cover a broader range of topics than what I normally would for a specialist meeting by concentrating on the work done by my colleagues and myself. I shall first describe salient features of the climate change when viewed as a scientific problem. I shall then describe the anatomy of a class of mathematical models that are particularly suitable for this area. I decided to include this topic because even if one is not involved in constructing models or applying them, one needs an appreciation of how models work in order to interpret their results. A brief description of component and system models of simple type as well as of general circulation type follows next.

Salient features of climate change

If we examine the records of temperatures, which are carefully constructed global averages of temperature data from extensive and diverse sources (e.g. Jones et al. 1986 for 1860-1983 and Hansen and Lebedeff 1988 for 1860-1985), we find changes of the order of fractions of a degree, some taking place very rapidly, say over a couple of years, and some rather slowly, that is, over decades. Systematic detection of a trend from such a time series is a tricky technical issue but it is not difficult to see that, roughly speaking, the average temperature has been increasing in the present century at a rate which is estimated to be 0.5 °C per century. It is also clear from examination of CO_2 data that the increase in CO_2 in the atmosphere in the present century is probably the single most important factor in the warming described as the greenhouse effect.

The problem of climate change is essentially the problem of the thermal behaviour of the earth system comprising the atmosphere, the oceans, the land, the

biosphere, and the snow cover (on the land or on the seas). This system is subjected to solar radiation with well-known diurnal and annual variations along with changes in solar activity as well as slower changes due to changes in the earth's orbit. Processes in the earth's interior affect the system mainly in the form of volcanic eruptions, which have an episodic effect detectable over several years. The complexity of the response of this system manifests itself in the effects spread over wide range of time and space scales. This variability is a consequence of several types of factors. First, the components of the earth systems have different time scales in their response as the dominant heat and mass transfer processes differ. Secondly, these heat and mass transfer processes are connected with complicated physico-chemical processes and, in some areas, with biological processes. While many of them are well understood, some are not (e.g. regulation of the transfer of carbon from the atmosphere to the ocean by photosynthesis in phytoplankton in the upper ocean). Thirdly, the interconnections amongst the components of the earth system are such that a change in one of them sets off a chain of events that leads to a change in other components, resulting in the original change either being intensified or reduced. Such linkages are called positive or negative feedbacks. Finally, some of the important processes are non-linear. It is only in the last three decades that we have begun to appreciate how an enormous variety of complex behaviour can arise from such processes.

Expectations of mathematical models

What do we expect mathematical models to do in this context? We would like these models to predict the climate change, to predict the effects of the climate change, to elucidate the role of anthropogenic factors in this change, and to elucidate the role of different processes. The first three capabilities would enable us to examine several scenarios representing different governmental policies and thus guide us to sensible action while the fourth one would enable us to refine the models as we go along.

Given the enormous complexity of the problem and the scope of our expectations, it is unreasonable to expect one master model to do everything for us. It is more realistic to have a tool-box of models, some advanced and some primitive, capable of doing many different tasks, each of a rather specialized nature. Their reliability would also differ, because such models can be validated only indirectly.

Types of models

Mathematical models relevant to climate change can be broadly categorized into process models and empirical or statistical models. In models of the first category, we describe the physical, chemical or biological processes quantitatively by incorporating general laws of nature as well as certain assumptions that cover gaps

in our knowledge or provide a gross representation of what is known, suppressing the details. In models of the second category, we seek relationships or patterns in observable quantities without attempting to describe the essential physical, chemical, or biological mechanisms the actions of which determine the observed quantities. For example, if we examine the record of temperatures (say average daily minimum temperatures in winter) in a city such as Delhi as a time series, we can construct a statistical model that can be used to predict winter temperatures in the city in a statistical sense. Similarly, we can examine wheat yields in Punjab and seek a correlation with temperature, precipitation, or soil moisture. Such models are useful in assessing the impact of climate change. They are also useful in extending the range of prediction of highly sophisticated models such as those based on GCM (General Circulation Models), which are very expensive to run. The rest of this talk deals entirely with process models.

Anatomy of a mathematical model

A mathematical model is a human construction with a definite purpose. To understand how a model achieves that purpose, let us consider the anatomy of a rather typical process model. It consists of a structure, a set of parameters which are given specific values, a numerical scheme for making calculations, and packaging, which handles the pre- and post-processing chores making the model easy to use.

The structure is the most important part of the model. It consists of a set of rules describing how the components of the earth system change with time. Most prominent of these are conservations laws. They describe how the mass of a constituent (e.g. air, water, carbon) or momentum or energy or population (e.g. phytoplankton) changes in a spatial region. These changes occur due to fluxes across the boundary of the spatial region. The fluxes can be diffusive (due to molecular process, due to turbulent mixing, or due to processes taking place on a scale smaller than that described in the model). The fluxes can also be advective, due to large-scale movement of fluid (air or water) across the boundary. Then there are radiative fluxes in the thermal conservation law. Changes in momentum brought about by surface force are described in terms of stresses. Changes taking place within the spatial region that contribute to the conservation laws are typically due to phase change, chemical reaction, body forces, and biological interaction (e.g. grazing). A conservation law typically states that the rate of change of a conserved quantity within the specified spatial region is equal to the net fluxes into the region across the boundaries and the rate of change due to processes within the region (e.g. grazing, chemical reaction).

In addition to conservation laws, there are other rules. There are descriptions too, of materials (e.g. equation of state), of processes (e.g chemical reactions, turbulence closure models, 'parameterization' for processes on scales much smaller

than those the model seeks to deal with), and of conditions on interfaces (e.g. fluxes across atmosphere and ocean).

Rules for a specific model are selected by the modeller, keeping in view the aspects of climate change to be modelled, the level of detail at which the model describes the earth system, and the available computing power.

When a calculation is made with such a model, one needs to specify what are called initial conditions, which describe the state of the earth system at some point in time. We also need additional information on the external forcing (e.g. solar radiation, absence or presence of volcanic eruptions) Thus, the predictions of climate change are always conditional. That is, if the initial conditions are as assumed and if the assumptions of external forcing are correct, then the climate determined by the model will be the future climate. Incidentally, the question of initial conditions has turned out to be extremely important. Clearly, if available data are used skillfully to construct initial conditions, it can enormously enhance the predictive capability of the model. Techniques called 'initialization' and 'data assimilation' are important research areas for sophisticated models.

Models and data

What is the relationship of data to the modelling activity? One has to determine the values of parameters used in models. Data are needed for exercises designed for this purpose, which are also called parameter estimation or calibration. One has to specify the initial conditions, which also needs data. One also has to go through validation runs to establish confidence in the validity or the applicability of the model. The more sophisticated the model, the more extensive data are needed for all these facts.

Component and system models

As modelling has evolved with increasing observations, one finds models that focus attention on some aspect of climate change, which are usually developed in a close linkage with a discipline. Thus we find models in atmospheric chemistry (e.g. carbon/ozone balance), atmospheric radiative transfer, atmospheric circulation, ice sheets, marine biological processes, hydrological cycle, etc. Some of these deal with only one or a few components (e.g. only the atmosphere) or seek bulk balance in several parts (box or reservoir models). System models, on the other hand, divide the earth system into components and describe the relationship between components as it affects the behaviour of the system. Some of the system models are quite elaborate. For example, a coupled atmosphere-ocean model with 2 1/2° by 3 3/4° resolution run for 75 years can take a couple of hundred days of supercomputer time! Not all system models are or need to be elaborate. At the other end of the spectrum, simple models may not divide the earth system into components at all or divide

it into only a few of them. For example, the famous model by Sellers and Budyko used thermal behaviour of the earth system on account of its intrinsic non-linear nature. A more recent example of a simple system model is that by Gilliland (1982) in which two components are considered. A lower reservoir represents deep ocean and an upper reservoir represents ocean mixed layer, atmosphere, and the land surface. Thermal response of this system to changes in solar activity, volcanic eruptions, and increase in CO_2 is determined for the period 1880-1980. The close correlation between the temperatures calculated by the model and the estimated earth temperatures is remarkable. Simple models thus help us in sorting out major issues and give us an insight into key factors. More elaborate models are needed for simulation and prediction. The present GCM-based models have evolved from the work of Manabe and co-workers at the Geophysical Fluid Dynamics Laboratory (e.g. Manabe and Wetherald 1980). In this approach, the radiation characteristics of the atmosphere are partly given (e.g. CO_2 in atmosphere) and partly calculated from climatological data. Heating of the atmosphere is largely associated with moist convective processes, which are parameterized. The atmosphere is divided into several layers and each layer is subdivided into segments of a few degrees latitude and a few degrees longitude. The ocean does not contribute to horizontal or vertical heat transport. What the model predicts for doubling of atmospheric CO_2 is significant warming near the poles, lower precipitation in mid-latitudes, and a slight augmentation of the hydrological cycle. Modern simulations give qualitatively similar results, although there are significant quantitative differences. Since there is significant spatial variability, what one seeks to understand is how the seasonal cycle of land temperatures, precipitation, etc. is modified in a chosen region as a result of changes in the levels of CO_2 (e.g. Wilson and Mitchell 1987). There is also some interest in determining how the frequency of extreme events is modified. Of particular interest are frequencies of droughts, storms, floods etc.

Some current research issues

At present, the coupled ocean-atmosphere models adjust the flow of energy from the atmosphere to the ocean, which is called flux correction. This adjusts the flux so that the departures of the flux and sea surface temperature from climatological values tend to decrease. This ad hoc procedure is a way of fixing a difficulty encountered in calculations of the coupled system, namely a drift from climatological values. Clearly, one needs a more rational procedure. Also, the resolution that can be handled at present is a few degrees, that is, a few hundred kilometers. This resolution is very coarse for the oceans as there are many energetic parts of the ocean (e.g. the Gulf Stream) with smaller spatial scale. Also it necessitates taking diffusivities that are much larger than what would be justified on physical grounds.

It is also recognized that we need to model the effect of sulphur emissions from

the oceans (e.g. Foley et al. 1991), which provide the nuclei for cloud formation, and other changes in clouds because of high sea surface temperatures.

Current research in India

While atmospheric circulation models are being used for several purposes in many centres in India, notably in Ahmedabad, Bangalore, Delhi, and Pune, ocean models related to climate issues are in their infancy as yet, though they are being developed in Bangalore, Goa, and Pune. Lack of high performance computing power has been a major constraint.

At the CSIR Centre for Mathematical Modelling and Computer Simulation (C-MMACS) in Bangalore, we have started work on a few topics related to climate change. Briefly, they are as follows:

- Simulation of atmospheric radiative transfer to study the effects of greenhouse gases, aerosols, and clouds.
- Marine ecosystem models related to atmosphere-ocean carbon flux problem.
- Conceptual system models.

Preparatory work is under way for basin scale ocean models as is related work on understanding the mechanism of generation of tropical storms in response to anomalies in sea surface temperatures.

Concluding remarks

Calculations with contemporary coupled ocean-atmosphere models give a quantitative picture of variations in seasonal cycle of temperatures, precipitation etc. due to changes in atmospheric CO_2 on the scale of several hundred kilometers. These results can be used for studies on the impact of climate change.

There are, however, several areas in these models, such as flux correction, that need further examination. Therefore, the results should be viewed as indicative rather than definitive.

Modelling studies on climate change on scales ranging from global to local involve pooling of knowledge from several disciplines. Training of young research workers in multi-disciplinary tasks calls for fresh approaches. Furthermore, sophisticated climate models make great demands on high performance scientific computing facilities.

Acknowledgement

I would like to thank my colleagues in C-MMACS, especially Dr Swathi and Ms Sharada, for their assistance in preparing this lecture.

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The IPCC scientific assessment of climate change: an overview

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The IPCC (Intergovernmental Panel on Climate Change) is a body composed of government delegates, which was set up in 1988 jointly by two UN agencies: the World Meteorological Organization and the United Nations Environment Programme. The object of IPCC was, and still is, to act in a scientific and technical advisory capacity to support discussions on international conventions on climate change.

IPCC decided that assessments in three areas were needed: the science of climate change, impacts, and policy responses. It set up three working groups under chairmanship of the UK, USSR, and USA to do this. IPCC asked Working Group 1 to prepare an assessment that was as up to date as possible, including our best estimate of how climate may change in the future, together with an estimate of our uncertainties.

The member nations of the WG1 (Working Group 1) met in January 1988, agreed about the scope of the assessment, and decided that its preparation would be entrusted to a number of lead authors, who would in turn involve a larger number of contributors through the mechanism of international workshops for each of the sections of the report. The lead authors met in March 1989 to define their task more closely and to agree upon a timetable. Many of the section contributors held short preliminary meetings in May 1989, and the latter half of 1989 was taken up by a parallel process for each of the sections: first drafts, followed by workshops to refine and agree upon a second draft. The drafts were combined into the first draft of the full report in February 1990 and modified at the week-long meeting of all lead authors in Edinburgh. This was then sent out to a large number of peer reviewers, and their comments were considered by the lead authors in preparing the final draft of the report. This was approved, at the second meeting of WG1 national representatives in Windsor in May 1990, together with a 30-page summary aimed at policy-makers (hence termed the Policymakers Summary), which had been through the same peer-review process.

The final report was delivered to IPCC in June 1990. In order to make the report widely available in the public domain, Cambridge University Press were asked to publish it, and this was available from September 1990.

The peer review process was an important part of the report preparation. The second draft was sent to scientists nominated by national delegates to IPCC (who circulated it further to other scientists), the members of Joint Steering Committee of the World Climate Research Programme, the Scientific Advisory Committee of the International Geosphere-Biosphere Programme, and, in addition, to about twenty other scientists. The large number of reviews undoubtedly led to considerable improvements in the final draft.

The 1990 report is therefore a comprehensive, authoritative, and internationally accepted assessment of current understanding of climate and climate change; its main conclusions are summarized in this paper.

Greenhouse gases

Firstly, the greenhouse effect as a physical mechanism is real. There is no doubt that increases in the concentration of greenhouse gases will warm the earth—we know this from satellite measurements, from planetary temperatures, and from the close association between temperature and greenhouse gas concentrations in ice cores.

We know that greenhouse gas concentrations have increased substantially due to human activity (Figure 1) and will continue to do so. We also know that many of the greenhouse gases have very long lifetimes or adjustment times in the atmosphere. CO_2 has a number of sinks, so its lifetime cannot be given a single number, but it is in the range of 50-200 years.

Figure 1. Changes in greenhouse gas concentrations due to human activities.

This also means that current concentrations are out of balance with emissions; even if emissions of CO_2 were stabilized at today's levels, concentrations would continue to rise; at 50% of today's emission rate, concentrations would rise less quickly; and even with no further man-made emissions, concentrations would fall only slowly (Figure 2). As a further illustration of the atmospheric response to emissions, WG1 calculated that to stabilize concentrations would require cuts of 70-90% in long-lived gases, and about 20% in methane. WG1 also used projections of future man-made 'business-as-usual' emissions (provided by Working Group 3) to estimate future atmospheric concentrations.

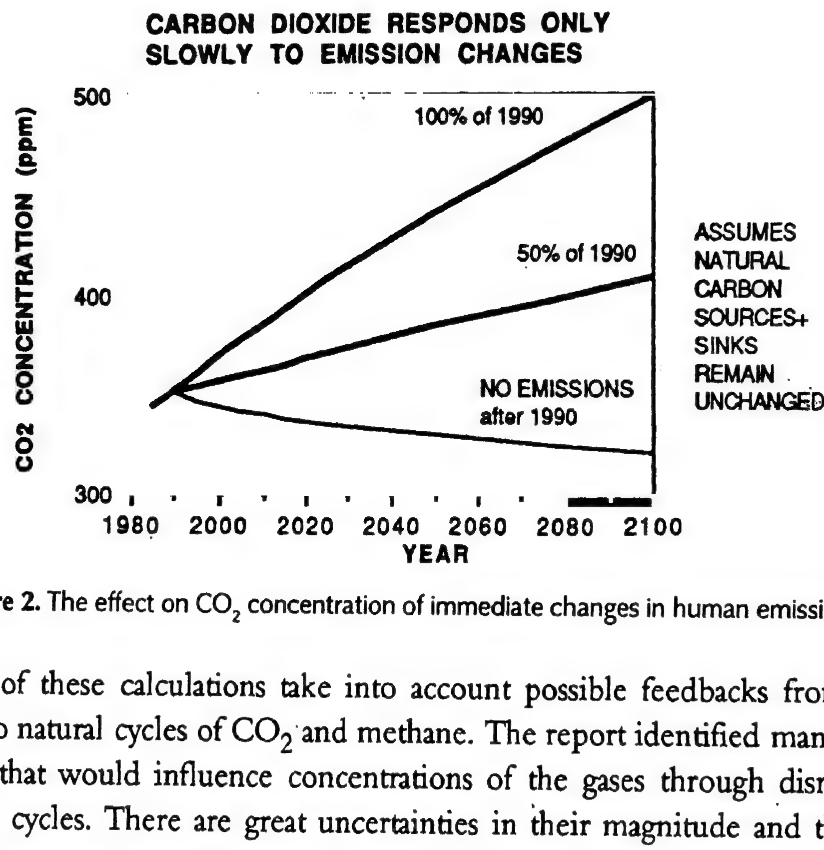

Figure 2. The effect on CO_2 concentration of immediate changes in human emissions.

None of these calculations take into account possible feedbacks from climate change into natural cycles of CO_2 and methane. The report identified many possible feedbacks that would influence concentrations of the gases through disruption of the natural cycles. There are great uncertainties in their magnitude and the Group chose not to try to quantify these; however, it opined that it seemed more likely that they were overall positive rather than negative, i.e. the greenhouse gas concentrations will be further enhanced by natural feedbacks.

Radiative forcing

The next state of the climate prediction process is to relate atmospheric concentrations to radiative forcing. This then enables us to calculate the increase in radiative forcing due to increases in the greenhouse gases during the decade of the 1980s. It is seen (Figure 3) that CO_2 represents half of the total change. The contribution from ozone could be significant but is too uncertain to quantify.

From a knowledge of their radiative properties and lifetimes, the relative effect

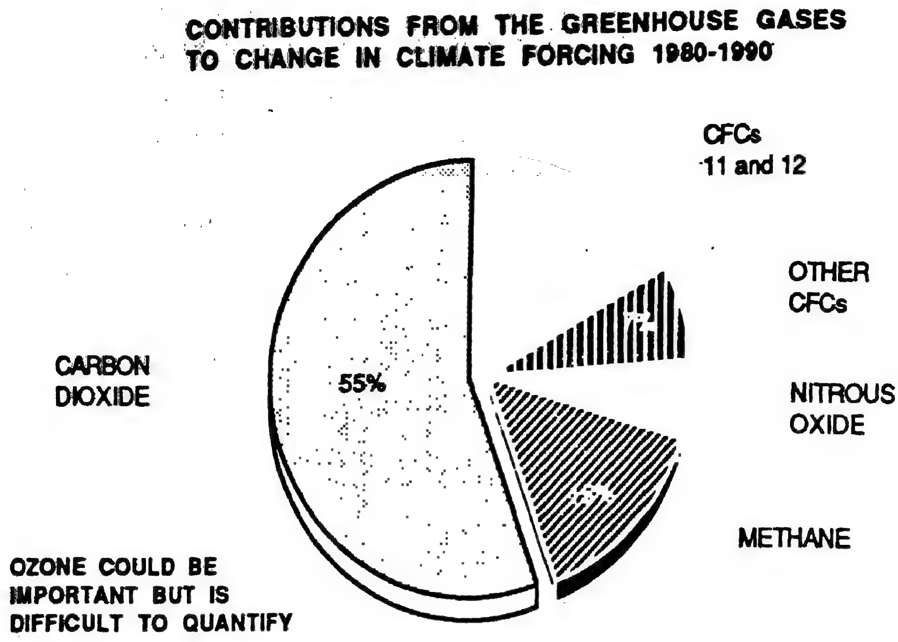

Figure 3. Contributions of the greenhouse gases to climate forcing over the last decade.

of equal emissions of each gas on the climate was calculated over a given time horizon —the so called the GWP (global warming potential) of each gas. This shows that over the next years, taking CO_2 as unity, methane has a GWP of about 30, N_2O about 300 and the CFCs several thousand (Figure 4).

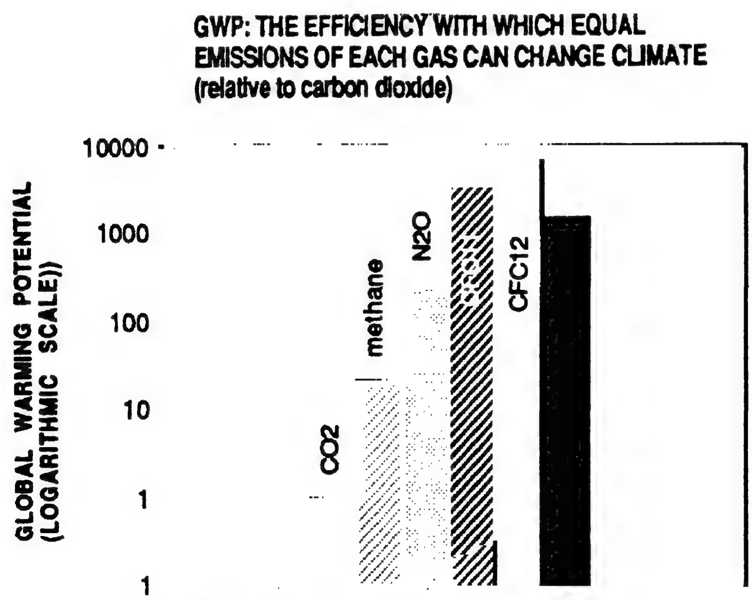

Figure 4. Global Warming Potentials.

This concept in turn allows the relative effect on climate over the next 100 years from 1990 emissions to be estimated. It is expected that, even more than in the past, CO_2 will dominate the increases in climate forcing (Figure 5).

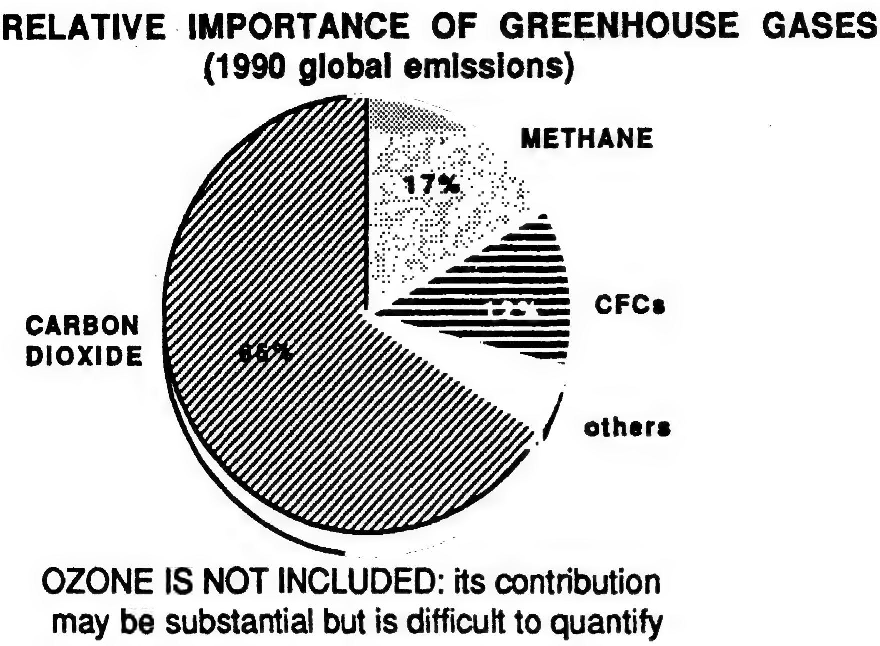

Figure 5. Contributions of the greenhouse gases to climate forcing over the next 100 years.

Climate change—equilibrium and transient

The next stage is to look at the actual climate changes arising from the increased radiative forcing. To start with, WG1 examined the results from 'equilibrium models' where the atmospheric concentration of CO_2 is doubled and the climate system allowed to come to steady state. The report finds some indication that the newer high resolution models are better at simulating present day climate, and hence might be expected to be better at predicting change. The general features of climate change that are common to most models and for which we have physical explanations are catalogued. The Group decided that there was no reason to change the value of the 2 x CO_2 climate sensitivity from the range of 1.5-4.5 °C that has been accepted for some time.

The report then considered the real world case of slowly changing forcing (as greenhouse gas concentrations slowly increase) and a climate system which is affected by the slow response of oceans. The projection of radiative forcing developed earlier was put into a box-diffusion upwelling energy balance model, and the best estimates of parameters such as ocean heat diffusion and climate sensitivity were used. The model output, of global mean temperature increase by 2100, is shown in Figure 6.

The report also looked at results from the first real transient climate integration using a coupled ocean atmosphere model, that of Manabe et al. at GFDL (Geophysical Fluid Dynamics Laboratory), Princeton. At a time of doubling of CO_2 in the transient run, the temperature rise is substantially less than the equilibrium case due to the delaying effect of the ocean. The ratio of this is typically 70%, but there are two areas where very little warming occurs, in regions where there is deep-water convection which act as a 'heat sink' and prevent temperature rising.

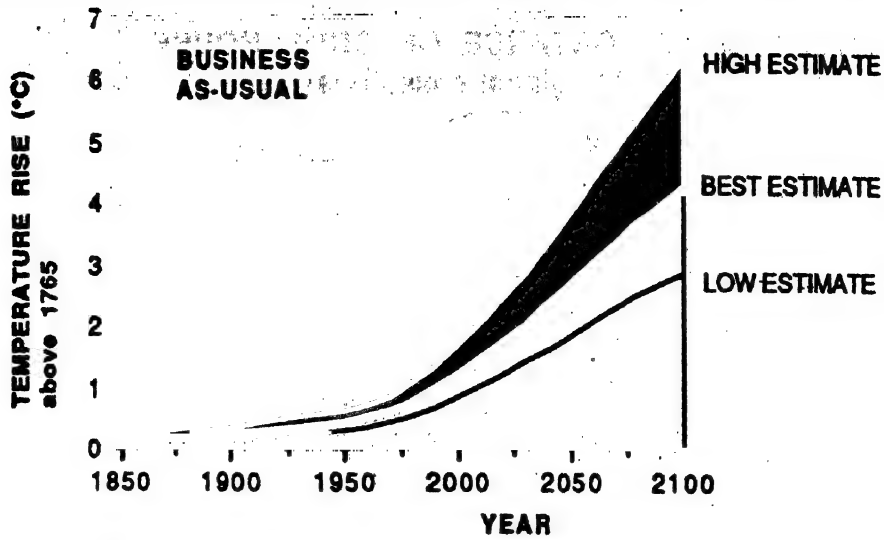

Figure 6. Model predictions of global mean temperature rise.

The conclusions from these transient integrations are that temperature will rise by 0.3 °C per decade (range 0.2-0.5 °C) in a 'business-as-usual' scenario; that oceans will warm more slowly than land surfaces; and that large areas of the northern Atlantic and Antarctic Ocean will hardly change.

Observations

Turning now to observations, the report concludes that global mean temperatures have shown great variability over the last 100 years, but have risen by about 0.3 °C-0.6 °C. The rise has not been steady in time or space. The two hemispheres have behaved quite differently, with a steadier rise in the southern hemisphere and a short cooling period in the northern hemisphere. The spatial pattern of temperature rise shows enormous variability at local scales, and this will surely be a feature of any future temperature rise.

Has the climate already changed due to man's activities? The evidence does not provide a clear answer. Considering global temperatures alone, the 'best fit' is with the low end of model simulations (Figure 7), but the comparison is complicated by natural climate variability, i.e. that which occurs without external forcing. This variability is deduced from models to be about 0.3 °C on a decadal time scale and, thus, could account for almost all of the observed increase. Alternatively, this natural variability and other factors could have offset a larger warming than has been observed. The unequivocal detection of the man-made greenhouse effect from simple temperature observations is not likely for a decade or more, but the use of more sophisticated 'fingerprinting' techniques could bring this forward.

Other climate indicators show some change: sea level has risen by about 10 cm over the last 100 years; glaciers have retreated on a global basis over the same period. However, there has been little change in the extent of sea ice.

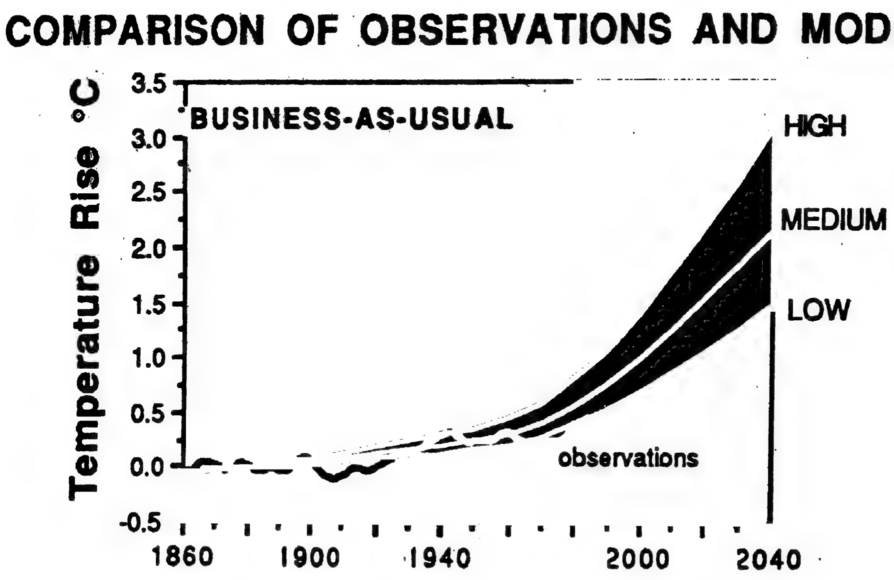

Figure 7. Comparison of model predictions and observations.

Sea level rise

How much do we expect the sea level to rise? Figure 8 shows predictions from the best models currently available, based again on 'business-as-usual' emissions; a rate of rise of 6 cm per decade is seen (with a range of uncertainty of 3-10 cm per decade). By the end of the next century rises of between 30 cm and 110 cm are indicated. The rise will not be uniform over the globe. The rise is expected to be due largely to thermal expansion of the ocean and melting of small glaciers. The net effect of the Antarctic and Greenland ice sheets may be small, but they make a major contribution to the uncertainty. Within the next century, it is not likely that there will be major outflow of ice from the West Antarctic ice sheet due directly to global warming.

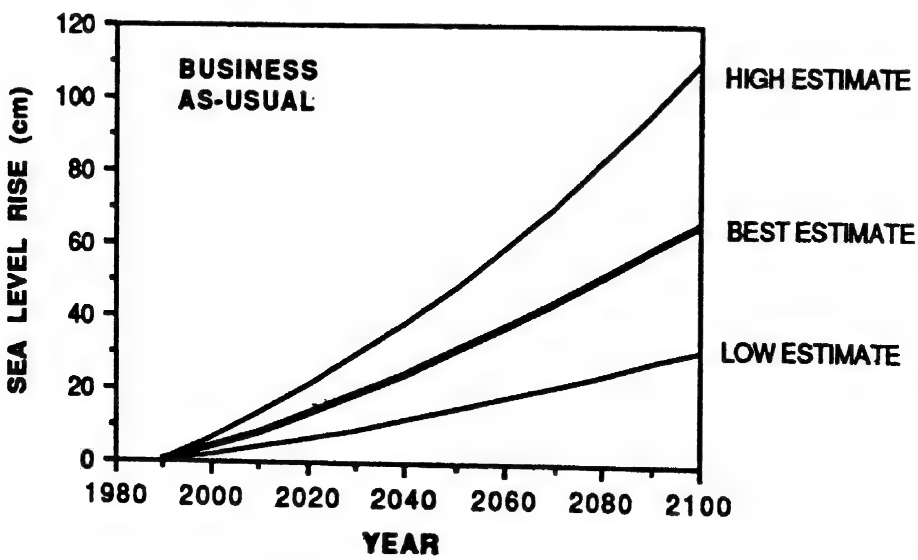

Figure 8. Predictions of sea level rise.

Uncertainties

All of the predictions are subject to great uncertainty due to our incomplete understanding of the climate system. The key areas of uncertainty are (a) clouds, changes in which can have a large influence on the climate sensitivity, (b) oceans, which control the rate of climate change, (c) natural greenhouse gas cycles, which could change to amplify or reduce the man-made influence, and (d) polar ice sheets, which affect predictions of sea level rise. Many large international programmes, under WCRP (World Climate Research Programme) and IGBP (International Geosphere-Biosphere Programme), are planned which will address these uncertainties. Because these processes are at least partly understood, we are confident that the uncertainties can be reduced by further research.

Further assessment

Because the pace of scientific research into climate change is accelerating, IPCC asked WG1 to prepare a short update to the 1990 Science Assessment by early 1992, before the UNCED (United Nations Conference on Environment and Development) in Rio de Janeiro. This work began in late 1990 and is now in its final stages.

From the viewpoint of the policy-maker, three factors stand out as most important. Firstly, scientists have demonstrated that the potential exists for considerable man-made climate change. Secondly, our predictive uncertainties are large and so we cannot rule out surprises. The 'ozone hole' is a painful reminder of how little we understand about our atmosphere. Thirdly, the long (100 years) lifetime of CO_2 and some other greenhouse gases means that any slowing down of their present rate of increase will be difficult, and reductions in emission made earlier will be more effective than those initiated at a later date.

The critical role of the oceans in climate change

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This paper reviews the critical role of oceans in influencing climate change and looks at some probable impacts. Oceans store and distribute vast quantities of heat. They also play an important role in the absorption of atmospheric carbon dioxide by both biological and physical processes. Climate change will probably accelerate existing rates of sea level rise, increasing the risk of coastal flooding.

Major international programmes are examining these three effects on a global scale. The WOCE (World Ocean Circulation Experiment) aims to determine fluxes of heat and the way in which circulation of water masses influences the climate system on time-scales from ten to one hundred years. The JGOFS (Joint Global Ocean Flux Study) is investigating on a global scale the processes controlling the fluxes of carbon and other biogenetic elements in the oceans. Sea level changes are monitored by the GLOSS (Global Sea Level Network); accelerated rates of rise due to global warming have been forecast by computer models of heat absorption and ocean thermal expansion.

In all these investigations a balance between ocean observations, process studies, and numerical modelling is essential for effective progress towards a reliable prediction of future climate variability and trends.

Introduction

There is no doubt that the oceans play a vital role in controlling the distribution of today's climate on planet earth. Their huge thermal capacity and inertia and their mobility, which enables them to transport heat from equatorial latitudes to polar regions, are critical factors in reducing climate extremes between low and high latitudes and from season to season. Future changes in climate will be related to future changes in ocean behaviour.

This brief account reviews three aspects of ocean dynamics that are particularly critical in studies of climate change and potential impacts. First we consider ocean

circulation, which is driven by winds and thermal forcing. Next we consider the possible role of the oceans as a sink for atmospheric carbon dioxide, a potential control of future greenhouse warming. Finally, we discuss the implication of global warming for sea level rise and coastal flooding.

Each of these three aspects will be related to known features of Indian Ocean behaviour, and to large-scale global programmes now under way, which will improve our understanding of the relationship between oceans and climate. These programmes all depend on a co-ordinated synthesis of process studies, observations, and numerical modelling of ocean behaviour.

Ocean circulation and heat budgets

As the oceans are warmed by solar radiation some of the heat is transmitted to the atmosphere, largely as latent energy in evaporation, and some is mixed with the deeper layers. Incoming radiation is much greater in the tropics than at polar latitudes and, if there were a locally balanced budget of radiation, the tropics would be substantially warmer than they are today and at higher latitudes it would be much colder. The more equable temperature distribution that we now enjoy is due to the transport of vast quantities of tropical heat to higher latitudes. Some of this heat is transmitted by the atmosphere and some by the oceans. Although the atmosphere transmits heat more rapidly, the much higher thermal capacity of the oceans makes them very effective carriers of heat energy: the relative role played in poleward heat transfer by atmosphere and by oceans is not known in any detail, but will certainty vary from ocean to ocean and with latitude (Carissimo et al. 1985). There will also be variation with time, from year to year and from season to season.

In the Indian Ocean the seasonal variations of ocean heat transfer are very strong. The Somali Current, a classic western boundary current in other respects, has a seasonal reversal that is not observed in other oceans (Luther and O'Brien 1985). From April to October the strong north-west current carries equatorial heat into the Arabian Sea, but from November to March there is a weaker current, flowing to the south. Ocean models are now able to reproduce the mean seasonal cycle of sea-surface temperature and heat flow in the north-west Indian Ocean quite well (Godfrey 1991), but the variability from year to year is not understood, nor are there sufficient data to allow predictions. It has been suggested that the southern gyre of the Somali Current is particularly prominent in years of good summer monsoon rain (Das et al. 1987).

For India, prediction of variations in the characteristics of the summer monsoon from year to year is critically important for agriculture and other development programmes (Biswas 1990, Nayak et al. 1989). Although a seasonal event, the south-west summer monsoon over India is well known for its variability on a wide range of time scales, especially its large variability on the inter-annual time scale (Satyan

1988). Kershaw (1988, 1989) has shown that for the monsoon of 1979, a better prediction of the onset was obtained by using the observed anomalously high temperatures of the eastern Arabian Sea in numerical models of atmospheric behaviour than when using climatological, averaged, temperatures. Joseph (1990) has suggested that the onset of summer monsoon rains over India is forced by a warm pool of ocean water that develops over the north Indian Ocean during May and June. Sadhuram et al. (1988) consider the importance of evaporation over the Arabian Sea for the inter-seasonal variability in the transfer of moisture across the west coast of India and conclude that only detailed information on evaporation and precipitation over the Arabian Sea during different phases of the monsoon could shed light on the problem. More recently Sadhuram et al. (1991) examined the relationship between pre-monsoonal sea-surface temperatures and subsequent monsoon rainfall over the west coast of India for observations in the period 1975-1984 and conclude that, statistically, higher than average sea-surface temperatures in the eastern Arabian Sea are not reliable indicators of an unusually wet monsoon season. Clearly there is a need for further studies of local ocean/atmosphere behaviour but Sadhuram et al. (1991) believe processes of global forcing must be incorporated into locally effective prediction systems.

Another possible example of local modification of a global signal through coupling between ocean and atmosphere has been suggested. Large-scale rainfall during the summer monsoon is associated with the ITCZ (inter-tropical conveyance zone). Over the ocean, the ITCZ and cloud bands preferentially occur close to the axes of maximum sea-surface temperatures (Joseph 1990). Observed 30- to 50-day fluctuations in the position of the ITCZ may be constrained by the positions of maximum sea-surface temperatures in the Arabian Sea and the Bay of Bengal but detailed studies are necessary to confirm this.

Statistically, there are clear relationships between Indian summer monsoon rainfall and the Southern Oscillation behaviour of the tropical atmosphere (Parthasarathy and Mooley 1986) over the past 100 years, which underlines the necessity for a global approach to developing prediction systems.

There are other aspects of Indian climate that can be related to the ocean process, including the development of cyclones in the Bay of Bengal, to which we return later. Shetye et al. (1991) have discussed the coastal current off south-west India, which reverses and flows north-west against the prevailing winds during November to January. In the eastern equatorial Indian Ocean and the Bay of Bengal, sea-surface temperatures are unusually high, and generally sufficient (greater than 28 °C) for organized convection and precipitation to develop. The heat balance, and the reasons for the high temperatures, are not well understood, nor is the influence of the very high influx of fresh water to the north of the Bay of Bengal.

These examples of possible influences on present day seasonal variability in Indian

climate also point to very sensitive responses to long-term trends in climate. For southern Asia, the IPCC (Intergovernmental Panel on Climate Change) (1990) suggested, very tentatively, that a warming of 1-2 °C throughout the year could occur by 2030. Given that ocean temperatures are now very close to the critical threshold of 28 °C for organized convection and precipitation, it is likely that substantial changes could occur in monsoon characteristics. Until more is known about the present day ocean-atmosphere coupling in the region, and the reasons for the large inter-annual monsoon variation that already occur, such predictions would be rather speculative.

The TOGA (Tropical Ocean and Global Atmosphere) programmes are a decade-long experiment to describe the large-scale transient variations of the tropical ocean basins and the global atmosphere and to determine the extent to which climate is predictable on time scales from months to several years. Attention has focused, with considerable success, on the observation and prediction of the El Nino phenomena in the tropical Pacific Ocean. Work in the Atlantic Ocean and the Indian Ocean has been less extensive, although it is recognized that both oceans have a large positive solar radiational heat flux which must be transmitted to higher latitudes by some dynamic mechanism (Godfrey 1991). The total circulation and heat transport of the oceans is being investigated in the WOCE.

WOCE is a major oceanographic contribution to the World Climate Research Programme of the International Council of Scientific Unions and the World Meteorological Organization. It is designed to study the important climate function of the ocean and to develop ocean models capable of predicting climate changes resulting from both natural and anthropogenic causes. Although the distinction is not exact, for the purposes of discussing changes in climate as a result of increasing greenhouse gases it is convenient to consider a 'fast' and a 'slow' component of climate (Needler 1991). The fast component includes the atmosphere and the upper ocean acting as a coupled system: the effect of evaporation and clouds on the radiation balance is a particularly important feedback process. Prediction of climate changes, by atmospheric circulation models coupled to shallow ocean models, suggest that for a doubling of atmosphere carbon dioxide, global surface temperature could increase from 2 °C to 5 °C—more in the polar regions than in the tropics (Mitchell et al. 1990). The slower component is due to the vast heat capacity of the global ocean and its slow response to surface changes. Sinking cold polar water circulates slowly at a depth on a time scale which varies from decades to centuries: global warming may be delayed, for the moment, by the thermal inertia of the oceans. WOCE will collect the observations to allow the development of full-depth ocean models so that the slow component of the response to changing greenhouse gas concentrations can be estimated.

Ocean measurements in WOCE will be made at sea and from space. Two

satellite-borne instruments are particularly important. The radar altimeter now operating from the European ERS-1 satellite will be joined by the USA/France TOPEX/POSEIDON. The topography of the sea surface, which they measure to an accuracy of a few centimetres, can be converted into current flow patterns in the same way that atmospheric pressure measurements can be used to plot winds. The scatterometer instruments, flown on ERS-1 and planned for the Japanese ADEOS, will give information on the winds over the ocean and the drag which these winds apply to the ocean surface. The drag, or stress of the wind on the sea surface, drives the large ocean gyres and boundary currents such as the Somali Current in the Indian Ocean.

Measurements from satellites are valuable because they provide synoptic global coverage of the oceans in only a few days, but the view they provide is superficial. In order to describe the interior of the oceans, vital for the slow component of climate change, other methods are needed. These include hydrographic measurements of temperature and salinity from the surface to the sea bed, from ships, as part of the WOCE Hydrographic Programme. Figure 1 shows (page 23 of WOCE) the planned ocean transects, most of which will be made once during the 1990-97 WOCE period. This will require 10 years of ship time, with a further 15 years of ship time required for other sections that are to be repeated several times during WOCE to measure ocean variability. Other measurements at sea include moored current meters, drifting oceanographic buoys, and measurements of sea levels, both to calibrate the altimeter measurements and to estimate currents from sea level difference between pairs of gauges on islands and across straits.

In the Indian Ocean, one of the key problems being considered in WOCE is the exchange of water and heat with the Pacific Ocean through the straits between the Indonesian islands. Flow of extremely warm water into the Indian Ocean reaches a maximum in August, but the effect of this heat flow on the budget and dynamics of the Indian Ocean is not fully understood. However, it is clear that inter-annual changes in the heat flow could contribute to variations of climate.

Biological and chemical fluxes

Increase in atmospheric carbon dioxide is found to be much less than expected from calculations of expended fossil fuel. Of the 5-6 billion tonnes of carbon added to the atmosphere each year by human activities, only 3 billion tonnes remains as increased atmospheric carbon dioxide. The oceans may absorb the remaining 3 billion tonnes but how and where this absorption takes place is not clear.

In terms of the overall ocean carbon budget, a possible 3 billion tonnes annual net flux is modest. Each year around fifteen times more carbon dioxide is taken up and released by natural marine processes than the total produced by the burning of fossil fuels, deforestation, and other human activities (Williamson 1990). Release

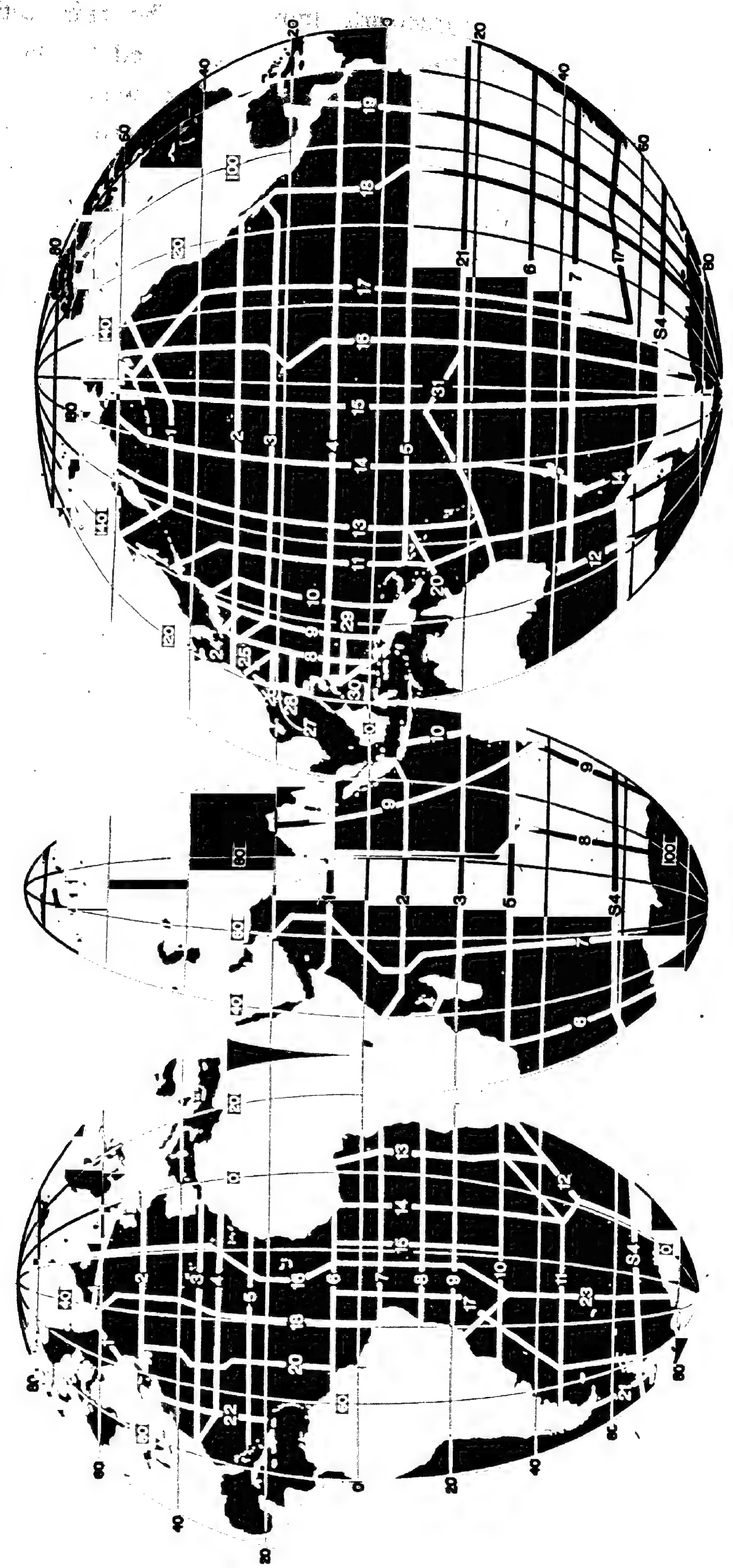

Figure 1. Distribution of WOCE one-time survey lines.

of only 2% of the carbon already stored in the oceans would double the level of carbon dioxide in the atmosphere. Nevertheless, estimates of the ocean take-up, based on observations, suggest that only 1 billion tonnes per annum is absorbed in the oceans. The accuracy of these estimates must be increased to allow reliable prediction of increases in atmospheric carbon dioxide and the related global warming due to the greenhouse effect. An international programme, the JGOFS, is currently under way to improve our understanding of the fluxes across the various interfaces: sea-air, the sea bed, as well as exchanges at the continental margins.

Although the amounts of carbon dioxide entering and leaving the ocean over an annual cycle are usually close to global balance, the exchanges are controlled by many different processes that operate over a very wide range of space and time scales. Air-sea carbon dioxide exchanges due to physical transfer through the surface are strongly influenced by the basic biological process of carbon fixation by photosynthesis in the surface layer and carbon dioxide release by respiration.

Phytoplankton, microscopic plants that develop by photosynthesis, the use of carbon dioxide, and the sun's energy in the near-surface layers provide the primary links between ocean biology and the atmosphere.

The partial pressure of absorbed carbon dioxide in the surface layers of the oceans controls the flux direction of the physical exchange. If the ocean partial pressure is greater than in the atmosphere, the ocean will have a net carbon dioxide loss. The details cannot be elaborated until we have much more extensive geographical and seasonal measurements but, in broad outline, carbon dioxide is absorbed by the oceans in temperate and sub-polar regions and released from the oceans to the atmosphere in tropical regions, particularly in the Pacific Ocean. At present it appears that the central and northern Indian Ocean are both areas of carbon dioxide release to the atmosphere. The rate of exchange depends critically on the surface wind speed, and it is expected that the satellite scatterometer data, discussed above for WOCE, will help refine the net global flux estimates (Etcheto and Merlivat 1988).

JGOFS studies in the North Atlantic Ocean in 1989 and 1990 show that carbon dioxide exchanges in spring and summer are dominated by the patterns of biological activity in the upper ocean. These biological activities in turn depend on the availability of sunlight and nutrients. There is a strong seasonal signal with a 'spring bloom' event, with rapid growth of phytoplankton following the development of a separate surface layer above the thermocline, and an increase in available light for photosynthesis. During a bloom event upper ocean carbon dioxide concentrations are closely correlated with biological activity measured in terms of phytoplankton abundance. At times of high productivity, the oceans are most effective at drawing down carbon dioxide from the atmosphere. Some of the carbon fixed during the bloom sinks to the deep layers of the ocean. The particulate organic and inorganic carbon that reaches the deep sea floor is subsequently degraded or dissolved by

biological and chemical processes that return inorganic carbon to the overlying sea water. The eventual return of that carbon to the atmosphere could take decades or centuries, as the deep water circulates and mixes slowly upwards. WOCE studies will help improve our estimates of this slow component of the climate engine. Some of the material that falls to the ocean floor accumulates in the sediment and is permanently removed from the global carbon flux cycle. One of the key questions for JGOFS is the significance of this removed carbon for stabilizing atmospheric concentrations of carbon dioxide.

The JGOFS scientists have identified the north-west Indian Ocean as an important area for the experiments, particularly those designed to study the changes in fluxes that arise from seasonally reversing monsoon circulation. The reversing monsoon winds cause dramatic changes in the biological productivity in this region; German and British scientists have recently studied these variations in some detail, but there is much work to be done.

During the south-west monsoon, the winds parallel to the coast of the Arabian Peninsula cause an offshore flow of surface waters. These surface waters are replaced by the upwelling of deeper waters, which are rich in nutrients. As a result this region is one of the most productive ones in the world oceans, with a regional maximum in the summer months (Zeitschel 1973). This productivity is clearly shown in satellite images which show the abundance of chlorophyll, the main phytoplankton pigment. High productivity extends over the whole of the north-west Arabian Sea, and also along the west coast of India (Williamson 1990). Potentially these are very important oceans for further development of commercial fisheries.

Changes in the pattern and intensity of the monsoon winds as a result of climate change could have a marked effect on the productivity of these areas. Dickson (1992) suggests that if ocean models indicate a strengthening of the south-west monsoon, then the upwelling will be altered. He calls for efforts now to establish a baseline of plankton measurements against which changes can be detailed, and the mechanism for change can be understood. Similarly any changes in monsoon characteristics will affect upwelling on the west coast of India.

Much of the carbon contained in the biosphere is concentrated in the coastal zone. In the United Kingdom, a new study (LOIS) of land-ocean exchanges has begun. In many of the Indian estuaries economically important ecosystems are established, and these could be influenced by climate change.

Most important, however, in densely populated low-lying coastal area is the potential danger of flooding as a result of sea level rise.

Sea level changes

Simple models of the oceans' responses to global warming suggest that sea levels of the world oceans could rise by 20 cm by 2030 and by 65 cm by 2100. Average

estimated figures of 6 cm per decade have a wide uncertainty of 3-10 cm per decade. Sea levels have risen by 15 cm over the past century. Expansion of warmer ocean waters and the melting of grounded ice are the principal contributors to the projected global rises, but even over the past hundred years the relative contribution of each factor is unclear. Melting of glaciers (Meier 1984) could contribute perhaps 5 cm of the observed increases. Fong (1991) has pointed out the anthropogenic influences in the form of reservoir and other forms of water storage could have reduced the observed mean levels by 3 cm in the period 1950-1990. Peltier and Tushingham (1991) showed that the effects of the last glacial recession will also have reduced the trends observed at coastal gauges well removed from polar regions. This is because of systematic increases in offshore water load produced by deglaciation. In other words, the coastlines of the world are still rising slightly. After making a correction for this effect, Peltier and Tushingham estimate a present rate of sea level rise of 2.4 ± 0.9 mm per year, substantially more than the average of the direct coastal observations.

The Peltier and Tushingham calculations show that post-glacial crustal movement is quite different at different sites. For the east coast of India they suggest a crustal uplift of about 1 mm per year; for the west coast their calculations show a lower rate of uplift, which falls to zero in the region of Bombay. They warn, however, that their calculations are extremely sensitive to modest alterations in the calculations procedure: more refined local calculations are required.

Direct coastal measurements of sea level have a long and distinguished history in India. A network of gauges has been operated by the Survey of India since 1877. Arur and Basir (1981) have published an analysis of sea level trends. There are many gaps and some stations no longer operate, but a summary of the trends for stations with more than 20 years of data is given in Table 1. On the west coast both Bombay and Marmagoa show positive trends. On the east coast Madras has shown a decline in sea level for the period 1954-1978 after a rise in the period 1895-1932. Das and Radhakrishna (1991) have published a recent review of the data and shown that upward sea level trends are only statistically significant at Bombay (1940-1986) and at Madras (1910-1911). Nevertheless, a complete review to include recent data as well as data from earlier years that have not been fully processed previously, would be appropriate.

Of course, these historical changes of sea level are not those predicted for future years under greenhouse warming. For these future levels we must rely on forecasts of global sea level changes and adjust these for local effects, particularly vertical coastal movements. Future rates of sea level rise are needed to allow progressive adjustments of social and economic systems (Pugh 1990).

When considering likely future sea level conditions it is important to realize that for coastal systems, the significant design parameter is the frequency of flooding

Table 1. Trends in sea level at station with more than 20 years of observations (from Arur and Basir 1981).

Port	Period of data	Trend (mm/year)	Standard error of trend
Kandla	1958-1978	4.06	1.18
Bombay	1878-1978	0.73	0.07
Marmagoa	1969-1978	1.62	1.50
Karachi (Pakistan)	1868-1946	0.74	0.12
Aden	1880-1933	0.07	0.13
Madras	1895-1932	1.12	0.44
	1954-1978	-1.18	0.93
Vishakhapatnam	1953-1978	0.16	1.12
Port Blair	1880-1920	1.83	0.27

to a particular critical level. An equal rise in the mean sea level at two different sites may not result in equal rise in their flooding frequency. Also, if one of the consequences of climate charge is a change in the pattern, frequency, and intensity of storms, then these could change flooding risks irrespective of what happens to the mean sea level.

The coasts of Bangladesh and West Bengal are already vulnerable to flooding from cyclone events and some of the most extreme catastrophes of modern times have occurred there. But the events of 1864, 1876, November 1970, and most recently, April 1991, will become more frequent as sea level rises. The flooding along the Indian coast in Orissa in June 1982 reached a peak higher than tidal levels of 4.5 m in the vicinity of Chandipur. Without careful analyses of winds and sea levels it is impossible to say with what frequency such events will recur. It would be valuable to undertake such an exercise and to examine old sea level records, when available, to estimate whether the statistics of storm and flooding have changed and to provide a baseline against which future changes can be identified. Numerical studies of the effects of raised sea level on surge propagation have been published recently (Dube and Rao 1991). They draw attention to the need for accurate maps of island coastal topography to make flood calculations, and the Indian Department of Ocean Development has already initiated a programme to generate high resolution topographical maps of some of the most vulnerable coastal areas on the east coast. Figure 2 shows the coastal tracts of India identified for such surveys as well as the network of modern digital tide gauges currently being installed for continual monitoring and modelling of sea levels.

The IPCC Report (1990) is unable to say whether there will be an increase or decrease in the frequency or intensity of tropical storms after global warming.

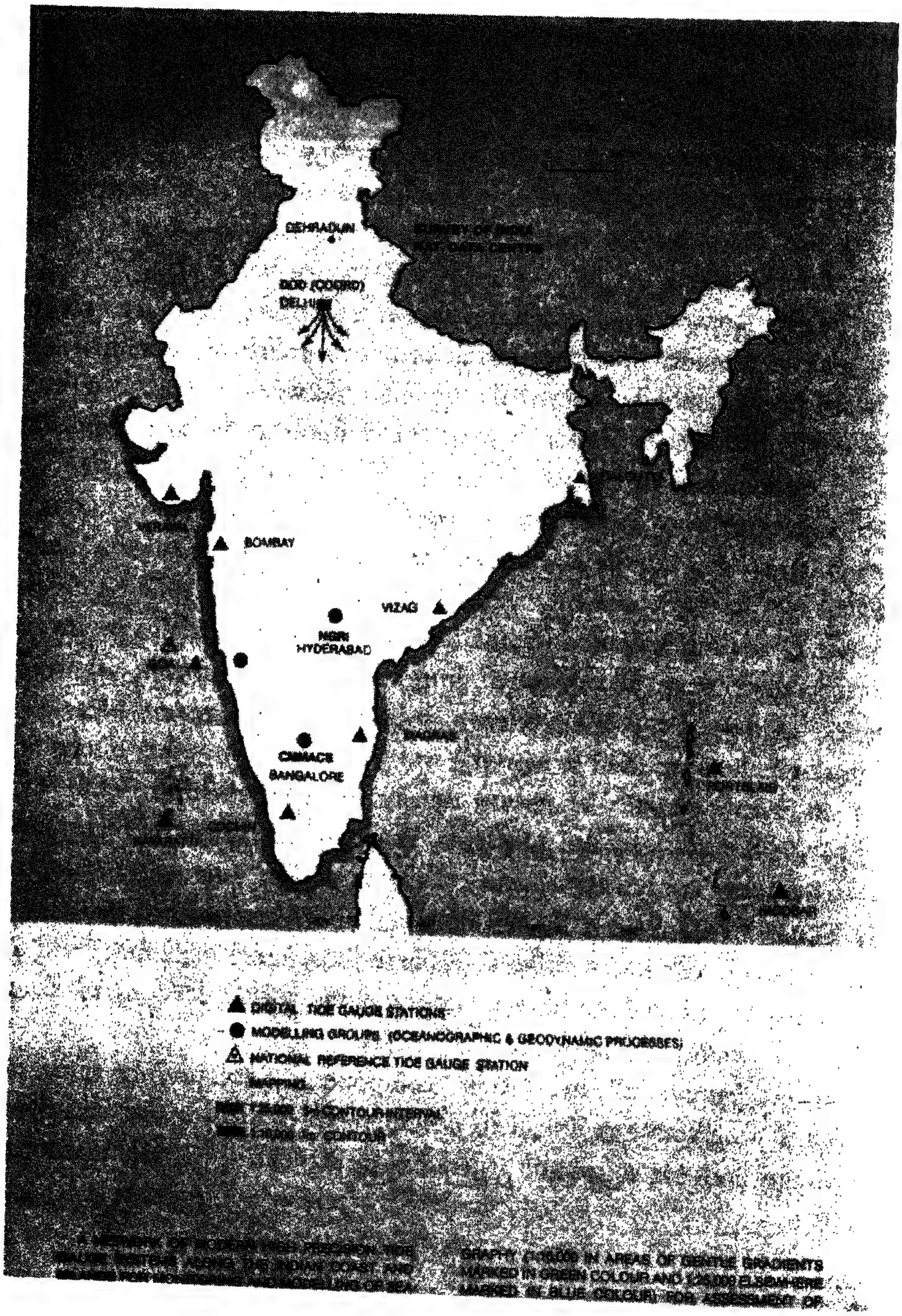

Figure 2. Monitoring and modelling of sea-level variations and implications to costal zone management.

Although larger areas of sea will have surface temperatures above 26 °C, the critical value for cyclone formation, they suggest that this critical value might itself increase in a warmed world. These processes and sensitivities need detailed scientific investigation.

The problem of predicting climate change: a systematic approach

In this final section, we propose to discuss aspects of the ways in which the problems of predicting climate change can be tackled scientifically, in the most effective way. Climate change has many aspects that relate to many scientific disciplines. In this account we have considered the close relationships between oceans and atmosphere but there are other factors: hydrology, agriculture, land-use, and ice cover, for example. Understanding of the climate system cannot be effective without regard for the human component, which involves economists, social scientists, energy experts and, if remedial measures are in prospect, politicians and their advisers.

The prospect could be overwhelming. The individual research workers need help to recognize the importance of their contribution to the total endeavour; and they need encouragement to link closely to adjacent disciplines, as oceanographers and meteorologists now do. Finally, we need to operate within a code of scientific responsibility, so that our knowledge and its limitations are effectively conveyed to policy makers. Scientific certainty was always an illusion, and politicians have long experience of dealing with uncertainty. Scientific responsibility also means avoiding sensational statements of extreme, improbable developments, although the temptation to help the press develop a good story is understandable.

Oceanographers are used to working with scientists from other disciplines. The staff of an oceanographic laboratory usually includes chemists, earth scientists, biologists, mathematicians, and physicists. Problems of climate change have given a new momentum and broadened this collaboration. The international programmes, namely TOGA, WOCE, and JGOFS discussed above are good examples as could be the proposed IGBP (International Geosphere Biosphere Programme), and GOEZS (Global Ocean Euphotic Zone Study). In many of the WOCE sections, measurements of the ocean system will be made for JGOFS.

These programme all have three components necessary for progress. An observational programme is linked to development of a modelling and prediction capability, and both are supported by studies of particular processes that the model represents.

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Short-term climatic fluctuations over India and ongoing efforts on climate change research

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1. Introduction

Climate of a country is a very important resource. India, with its geographical location in the tropics and subtropics, enjoys a variety of climate that changes from the extremes in northern India to near-equatorial climate over the southern parts of the country. However, India is known for its monsoon climate and whenever we speak of the climatic fluctuations over India, we are mainly concerned with the fluctuations in the monsoonal rainfall regime. Monsoonal climate in its various manifestations has affected the Indian society in all aspects: culturally, socially, economically, historically, and even religiously. Over the past few decades, issues related to climate change are being debated publicly at national and international levels. The human society in living memory has enjoyed a particular type of climate and is able to adjust to minor fluctuations within this climate range. However, man by his industrial activities has added new dimensions and is now considered to be capable of altering the chemical composition of the atmosphere which basically controls the global climate. Climate, thus, is no longer considered robust; concern is growing about the fact that human activity is making the chemical composition of the atmosphere increasingly fragile.

On a regional or local scale, climate is modulated by several physical features of the environment. Global and regional climate changes along with the significant changes in regional climate due to global warming have created a tremendous interest amongst the experts. A variety of climate change scenarios have been projected. The questions being asked to the atmospheric scientists are: What has happened to the climate? What is happening to the climate? What is going to happen to the climate? What steps are being taken by the atmospheric science community to understand and monitor the Earth's climate?

The paper is mainly concerned with a review of short-term fluctuations in the monsoon climate of India. In Section 2 we deal with aspects relating to the variability

of monsoon rainfall on different time scales, based on historical, dendro-climatological and instrumental records. Section 3 provides a brief summary of the climate scenario for the monsoon climate of India as obtained from the analogue studies and as based on the results from the atmospheric general circulation model. In Section 4 we provide some details about the steps the atmospheric science community has taken internationally and nationally to understand and monitor the earth's climate. The role played by India in this effort is also highlighted. A summary of the paper is given in Section 5.

2. What has happened to the monsoon climate?

Scales of climate variability and forcing mechanisms

Global, regional and local climates are not static but change on different temporal scales. These changes are brought about by variations in different components of the climate system which consists of the atmosphere, the oceans, biosphere, cryosphere, and lithosphere. These components are highly interactive on different scales; fluctuation in one or more of the components would affect global, regional, or local climate appropriately. The basic forcings for the global climate system are radiation, chemical composition of the atmosphere including aerosols, and physical features such as orography, land-sea contrast, forests, ice sheets, and ozone in the stratosphere. Living generations are intimately concerned with the immediate history of climate, say over nearly 30 to 100 years. However, each generation leaves its own account of the climate fluctuations and these historical records tell us about the changes witnessed in the long-term climate history of a country.

For understanding climate change systematically, atmospheric scientists have divided the temporal scales into increasing orders of magnitudes, starting from a 10-day scale. For example, for the study of climate variability on 1-10 days scale, we need information about daily variations in the climate parameters; shorter fluctuations in weather, e.g. thunderstorms, are considered noise. To study the changes in a 10-100 days time scale, we are interested in monthly and intra-seasonal changes. Signal is based on the monthly or seasonal means; sub-seasonal variations are treated as noise. For the next higher scale of 100-1000 days, our interest lies in annual and inter-annual changes in which phenomena such as the ENSO (El Nino-Southern Oscillation) and Himalayan/Eurasian snow cover become important. For the 1000-10000 day scale, our interest shifts to inter-decadal changes in the climate; on this scale, inter-annual changes such as the ENSO become noise. When the description of climate on the scale of thousands of years and beyond involving the glacial and interglacial periods become significant, the decadal and century means are treated as noise.

The forcings of climatic fluctuations change with time scale of variability. For example, climate on the scale of days is basically controlled by internal dynamics of the atmosphere which bring in changes in day-to-day weather. For the inter-annual and decadal scale changes, the atmosphere and the oceans and to some extent the lithosphere become the forcing mechanisms. For regional and global scales of climate fluctuations, certain modes of climate variability become apparent on inter-annual time scales. Some of these modes are explained through teleconnections, which are a fundamental feature of atmospheric variability. Changes on the scale of a century or longer are controlled by interactions of components not only within a climate system but also those external to the climate system, such as solar variability and changes in the Earth's orbital parameters.

For constructing the climate records on daily, monthly, seasonal, and inter-annual scales we are mainly guided by the observations recorded from meteorological instruments, which began in the 19th century in many countries. For this purpose we also use atmospheric global circulation models to perform sensitivity experiments to understand how different physical parameters affect the variability of climate. We can also study climate change on decadal and centenary scales by using substitutes to records such as historical documents, dendro-climatological evidences, and studies based on pollen grains. For periods beyond centuries our database for climate studies depends on lake levels, ice cores, ocean sediments, paleomagnetism etc.

Variability in monsoon rainfall of India

Thousands of year scales

Over the Indian region there is evidence of appreciable climate changes in the past for which reliable data are available from the north-western region of India. On the basis of studies on the Himalayan vegetation, lake levels in Rajasthan, and other historical evidences (Pant and Maliekal 1987) we notice that India passed through extended periods of increasing warmth, optimum warmth, and decreasing warmth. Such extended periods are linked with the passage of glacial and inter-glacial epochs. We have evidence to suggest that India also witnessed an extended wet period during which monsoon would have penetrated farther north-westwards. Similarly during extended dry periods the monsoon was weak and restricted its activities close to the equatorial region.

Evidence of monsoonal fluctuations on inter-annual and decadal scales based on data from instruments

Scientific observations of meteorological parameters in India began with the establishment of an observatory in Madras in 1802. In the first half of the 19th century this system extended rather slowly. However, with establishment of the IMD (India

Meteorological Department) in 1875, the meteorological work in the country was organized on a sound footing and in the next 100 years or more the meteorological observational system has expanded tremendously in scope as well as scale. Luckily for us, the recorded data from these observatories have been well preserved and are available to us to understand the monsoon variability on daily to decadal scales. Right from the early years of the IMD, when Dr Blanford wrote his classic memoir on the rainfall of India in 1884, Indian monsoon rainfall has been studied by a large number of workers within the country as well as abroad. Performance of the monsoon on inter-annual scales has been linked with a variety of parameters and recently (Gowariker et al. 1989, 1991) the problem has been approached taking into account 16 parameters. The northern hemispheric surface temperature is one of the parameters (Verma et al. 1985). Figure 1 shows the variation of the northern hemispheric annual surface air temperature and Indian summer monsoon rainfall. Although we do not see any consistent long-term association between these two series, studies suggest that warmer temperature in the northern hemisphere during winter led to subsequent better performance of monsoon.

Recently Parthasarathy et al. (1990) have built a homogeneous rainfall series of India based on the records since 1871. Figure 2 presents these data. It is seen that the rainfall fluctuates on inter-annual scale with a seasonal mean of 85.2 cm and standard deviation of 8.3 cm. Large departures from the long-term mean, generally one standard deviation and more above and below, are designated as flood and drought years respectively. There is no pattern to the occurrence of drought or flood years; they occur rather randomly (Thapliyal and Kulshrestha 1991). They are, however, influenced by a variety of factors as indicated in the study by Gowariker et al. (1989, 1991). The series has been recently expanded by Sontakke (1990) to as back as 1813 with the varying records of stations. Her study shows that correlation coefficient of all-India monsoon series based on 306 stations and extended monsoon rainfall series reaches the value of 0.9 when 10 or more widely spaced stations are considered for averaging. As such, this extended rainfall series could be relied upon to understand monsoon fluctuations from 1846 onwards at least. Figure 3 shows this extended rainfall series and it is clear that the fluctuations between 1813 to 1870 are within the same margin as after 1870.

Figure 4 shows the distribution of decadal average series for the period 1814-1988. The decadal series mean is 84.6 cm but the standard deviation of the series is only 2.0 cm.

Thus, reliable records indicate that though there is a considerable variability in the monsoon rainfall on inter-annual scale, the variability is considerably reduced when we average the data on decadal scales. There have been extended decadal periods when monsoon rainfall was below one standard deviation of the decadal average. They have occurred in a period for which data from meteorological

instruments are available and it is expected that they could occur again. For the recent decade the average rainfall is only marginally less than the long-term average. However, we know about the hardships India had to face during the decades 1970-90 owing to severe droughts. This is because our economic dependence on monsoon rainfall has increased due to population explosion and industrialization.

Table 1 lists the years of major large-scale droughts over India since 1782. It can be seen that there have been as many as 9 occasions when three droughts occurred in a decade and only one occasion when four droughts occurred in a decade. Mooley and Pant (1981) have fitted the Poisson probability model to the observed number of drought records since 1771. Their study shows that there is a possibility of three drought years within a decade. However, when the decadal variability is small it would mean that Indian monsoon rainfall fluctuates in such a manner that the remaining years of a decade would perform close to normal. This behaviour of the Indian monsoon rainfall is due to the fact that the ascending limb of the Indian monsoon system lies in the deep moist tropics and as such, unlike the Sahel rains, the Indian monsoon is unlikely to perform adversely over extended periods of a decade.

Table 1. Major large-scale droughts over India (1782-1987).

1782	1783	1791	1802	1803	1806
1812	1823	1824	1832	1833	1837
1838	1844	1853	1860	1865	1868
1873	1876	1877	1896	1899	1911
1918	1920	1941	1951	1965	1966
1968	1972	1974	1979	1982	1986
1987					

Updated from Mooley and Pant 1981

Pant et al. (1988) have reconstructed the monsoon rainfall series of India using statistical models of dendro-climatological data of North America and the southern hemisphere, and the southern oscillation records. Figure 5 is taken from this work which again indicates that Indian monsoon rainfall has fluctuated in the last 400 years within the same limits as in the recent past. Thus further confidence is generated that the rainfall of India is fairly stable and apart from inter-annual fluctuations, variations on decadal scales are rather minimal. In view of what has been discussed above, the monsoon rainfall series has now become an important indicator in predicting climate change in the future.

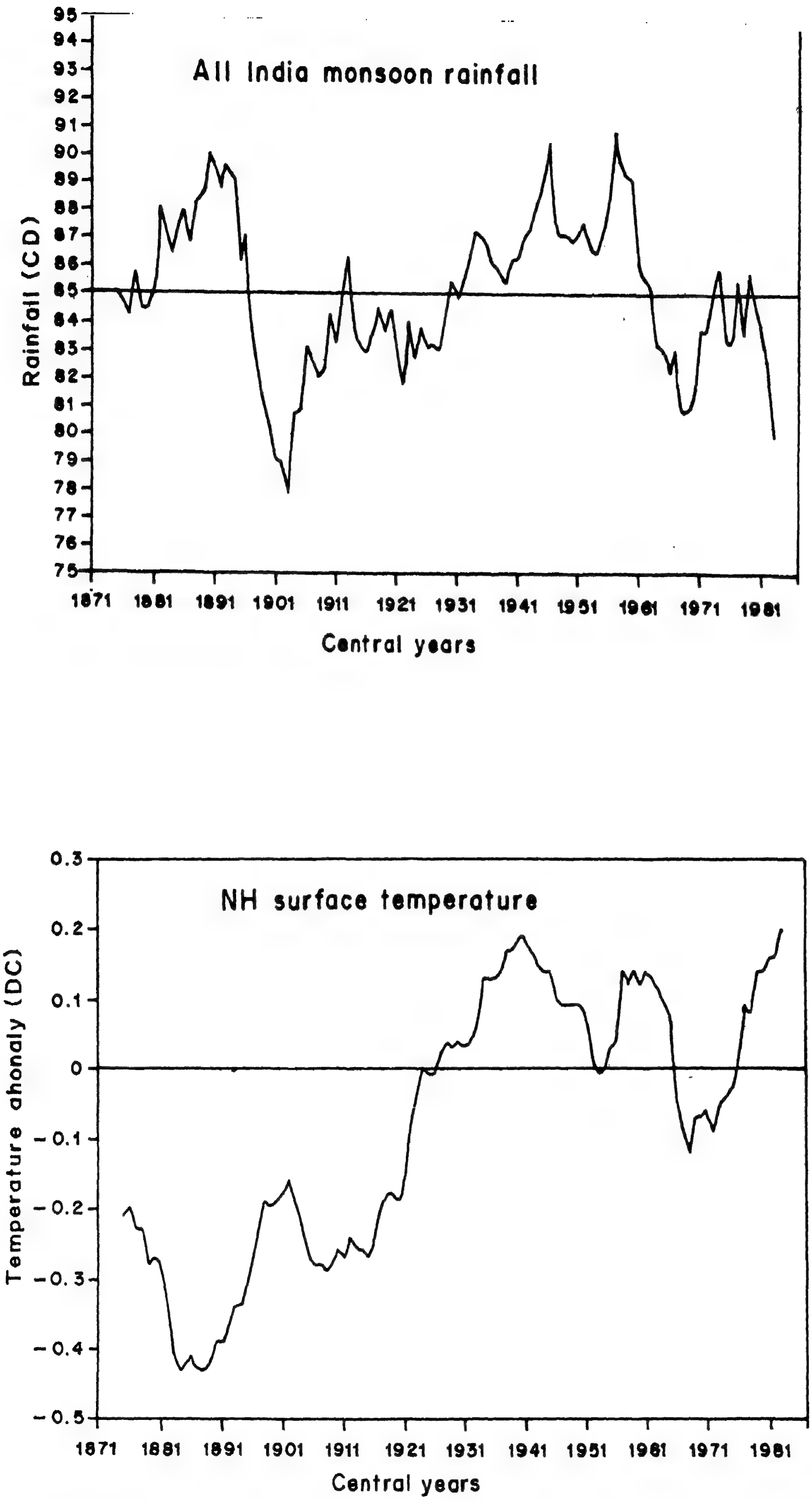

Figure 1. All-India summer monsoon rainfall and northern hemispheric surface temperature series smoothed with a 9 point Gaussian low pass filter.

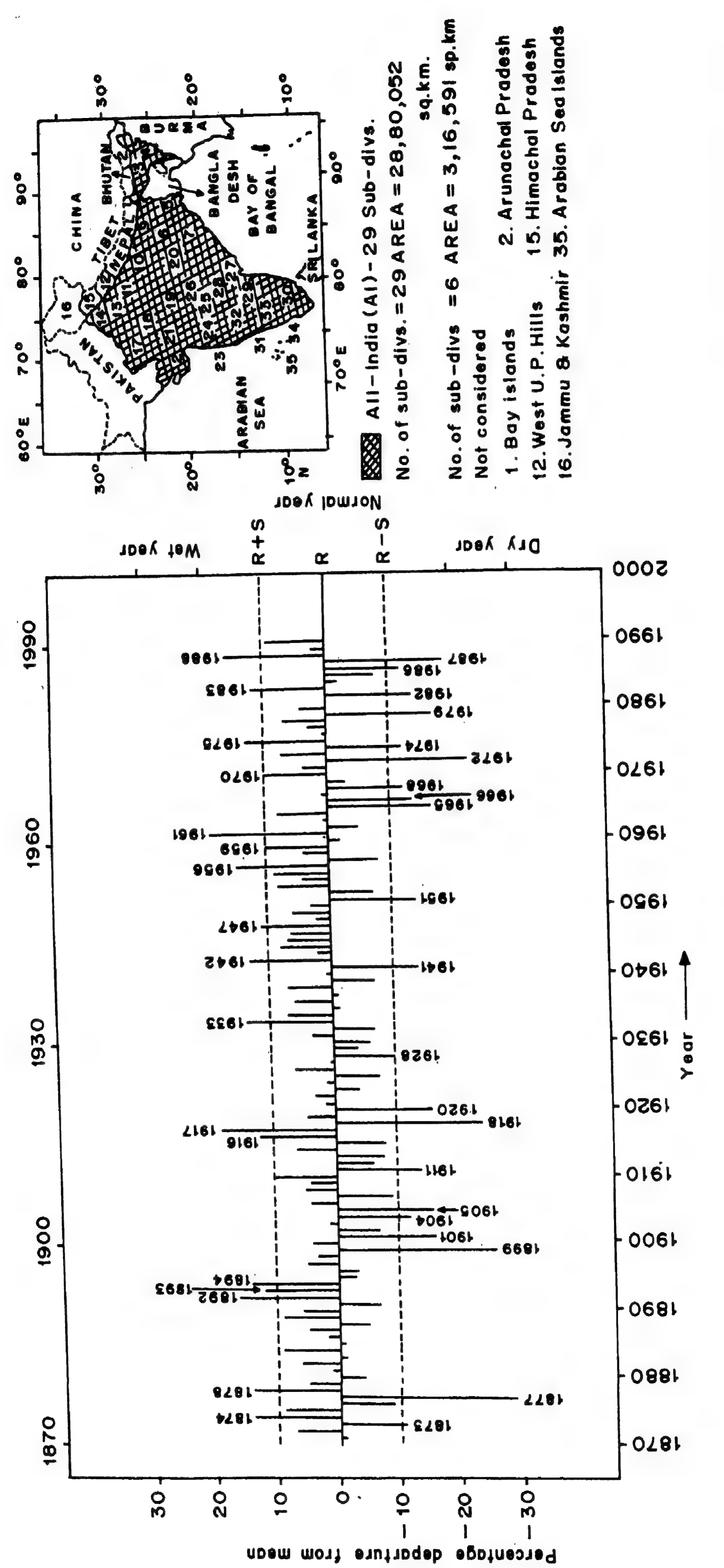

Figure 2. All-India summer monsoon rainfall series based on 306 stations over the plains of India (1871-1990) (*After* Parthasarathy et al. 1990).

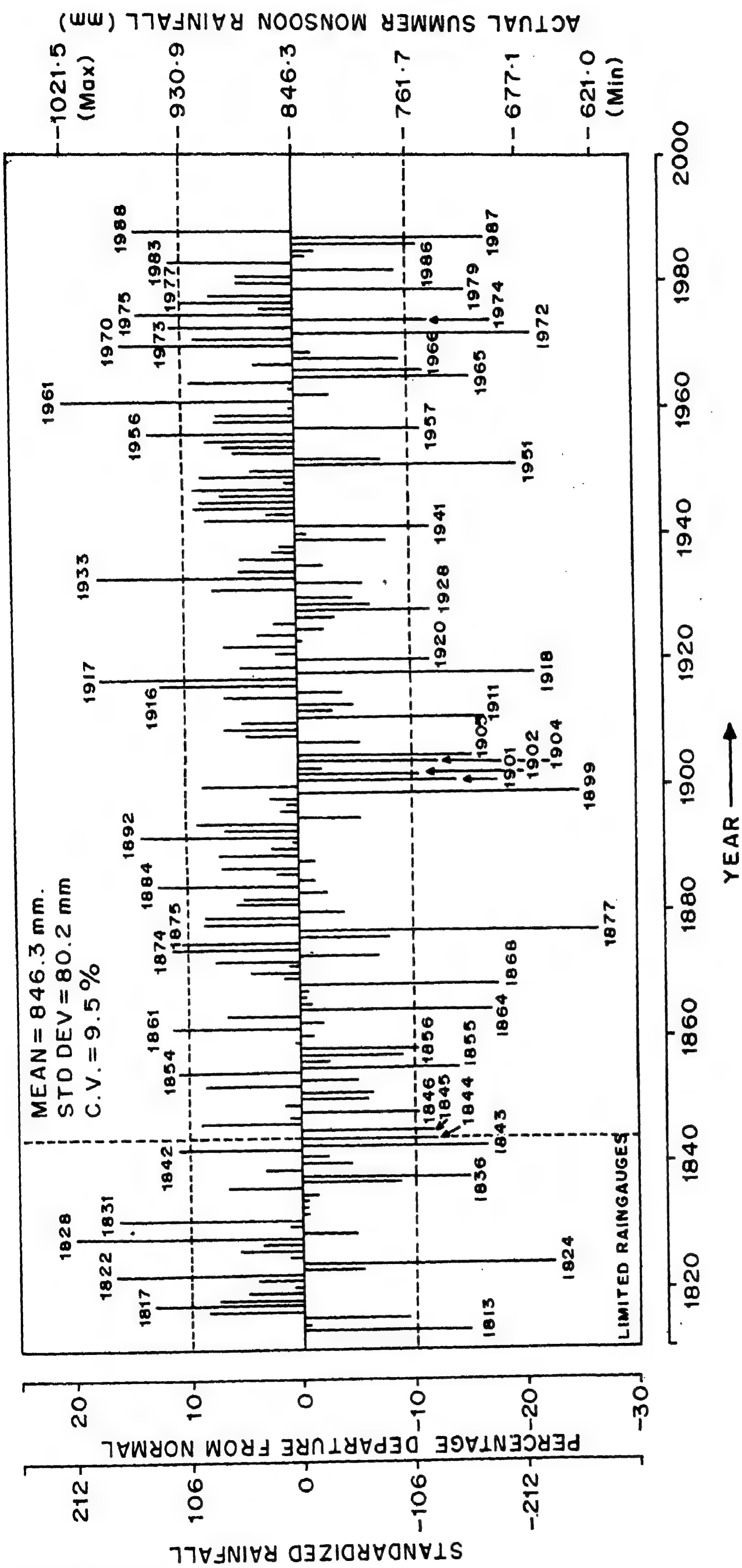

Figure 3. All-India summer monsoon rainfall series for the period 1813-1988 (*After* Sontakke 1990).

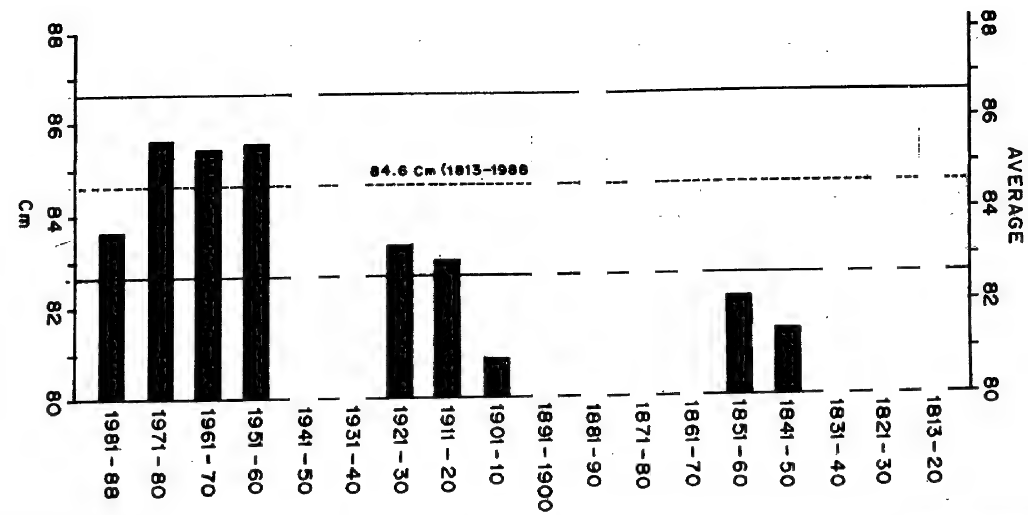

Figure 4. Decadal scale variability of Indian summer monsoon rainfall for the period 1813-1988 (*After* Sontakke 1990).

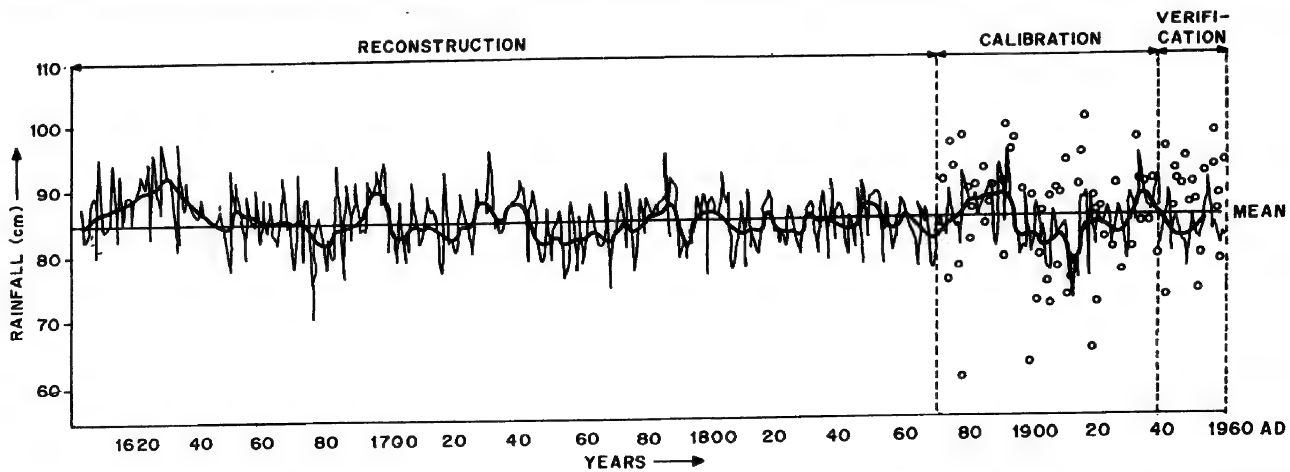

Figure 5. Reconstructed series of all India summer monsoon rainfall (1602-1960) with 9 point Gaussian low pass filter (thick curve). The circular points indicate actual rainfall. (Reconstructed based on tree-ring Southern Oscillation—monsoon rainfall relationship.) (*After* Pant et al. 1988).

3. Monsoon rainfall scenario

Past analogues

As mentioned earlier, some relationship exists between surface temperatures in the northern hemisphere and the rainfall in India. Therefore we could adopt the analogue approach to understand the influence of warm/cold epochs in the northern hemisphere on the performance of the monsoon.

Sikka and Pant (1991) adopted this approach. Based on their studies of the departure of the decadal means of these parameters from the long-term averages in respect of monsoon rainfall on one hand and the northern hemisphere and Indian air temperature anomaly during winter on the other, they concluded that although warmer and colder decades could be generally associated respectively with higher and lower monsoon rainfall, the relationship is not very consistent. Similarly, they also built analogue for the 10 warmest (and coldest) winters in the northern hemisphere and rainfall in India as well as for the 5 warmest (and coldest) years since 1950.

The study showed that the relationship between the temperature anomaly and rainfall on individual year basis is rather strong such that the higher and lower surface temperatures lead respectively to higher or lower rainfall. However, there are also exceptions to this. For example, in 1987, which was a warm year, India suffered a drought in the monsoon season and in 1917, which was a cold year, the Indian monsoon performance was much above the normal. However, the study points out that Indian rainfall is expected to be higher than its present normal during the extended period of warmth.

Atmospheric general circulation models

Comprehensive physical/numerical model of the atmosphere and the oceans (GCMS) is an accepted tool for simulating and understanding the behaviour of the climate system and its components. Models are sophisticated techniques for solving governing non-linear partial differential equations and in their treatment of physical processes important to the system. Remarkable success of the models shows that it is possible to deduce the 3-dimensional structure of the atmosphere, the oceans, and the earth's surface with reasonable fidelity.

Basic numerical techniques in different models are relatively standard. Horizontal resolution of the models varies by a factor of 25 and vertical resolution of the models varies by a factor of 25. The vertical resolution varies from 2 levels, the minimum possible, to 20, a factor of 10. Thus the range of total number of grid points is 6500 to about 1 million—a factor of 150.

Various uncertainties and approximations made in formulating and solving the governing equations result in characteristic deficiencies in climate simulations.

Climate models are in a state of continued and accelerating evolution and improvement and efforts to compare the various models promote further research.

These models have been increasingly used in the last decade to understand the climate changes that are being forced due to anthropogenic effects. The validity of these models to simulate regional climate anomalies such as monsoon climate may not be very high. In the present study the equilibrium climate change for the doubling of CO_2 scenario over the Indian region is examined using three models. The details of the models are described by Schlesinger and Mitchell (1987). Table 2 presents the change in climatic parameters over the Indian region as demonstrated by three GCM simulations for the doubling of CO_2 scenario. The study shows that the surface temperature over India is expected to increase by 1 to 3 °C during

Table 2. Changes in climatic parameters over the Indian region as demonstrated by GCM simulations for doubling of the CO_2 scenario.

Climatic parameters	Models GFDL	GISS	NCAR
	DJF (Winter)		
Temperature	Increase 3-4 °C	Increase 3-4°C	Increase ~2°C
Precipitation	Slight (< 1mm d^{-1} decrease in north and increase in south)	Increase 1-2mm d^{-1}	Increase (1-2 mm d^{-1} in north, 1mm d^{-1} decrease in south)
Soil water	Decrease < 1 cm	Decrease < 1 cm	Increase 1-2 cm
	JJA (Monsoon)		
Temperature	Increase 2 °C	Increase 1-2 °C	Increase 2 °C
Precipitation	3mm d^{-1} increase (mainly over eastern India)	1mm d^{-1} decrease	1-2 mm d^{-1} increase
Soil water	Slight increase	Slight decrease except at high northern latitudes	Slight increase except a slight decrease in the Himalayas

(After Sikka and Pant 1991)

summer and winter respectively and precipitation during the monsoon season is likely to increase by 1-3 mm per day (i.e. 10 to 30% in a monsoon season). Recent work by Lal (1992) using the Max Planck Institute climate model also indicates that in the warm globe situation under the 'business-as-usual' scenario, monsoon rainfall over India is likely to be higher by about 10% of its present value. Thus GCM studies point to higher than normal rainfall ranging between 10-30% of the present value over India. Though there is a large uncertainty about this scenario, the models do indicate that the rainfall is likely to be on the higher side of the present normal. Adjustment of the present regional ecosystem to marginal increase in the rainfall would not pose any problem. The situation could be different if the rainfall increases by 30%. In such a situation the flood plains of northern Indian rivers would expand and the intake of fresh water into the Bay of Bengal would increase. Agriculture in that case would have to adjust to new levels of temperature, rainfall, cloudiness, and ground-water. The implications of increased discharge of fresh water into the Bay of Bengal on ocean and atmospheric circulations are required to be assessed.

4. Efforts of the atmospheric scientific community to climate research

During the last four decades and particularly since 1978, atmospheric scientists have devoted considerable efforts in grappling with the problem of understanding and ultimately predicting the short-term climatic fluctuations or changes on global and regional scales. For these efforts they have used the comprehensive atmospheric general circulation models, ocean models, coupled ocean-atmospheric models, and cryospheric models to simulate the present and the past climates as well as to judge the sensitivity of the climate to various physical processes such as change in the composition of greenhouse gases, lower boundary conditions to the atmosphere, land-surface processes etc. They have also introduced at the international level mechanisms for comparing the results of global climate models and for developing strategies to carry out specific sensitivity studies. Also, a variety of climatic data centres have been established under international and national efforts to archive and retrieve high-quality climatic data about a variety of parameters. Special observational programmes to study the processes relevant to the climate problem are being organized, and emphasis is being laid on dedicated land-, ocean-, and space-based climate observational systems. In the following paragraphs, we summarize these efforts so as to put in proper perspective the entire gamut of out present attack on the problem of climate understanding and prediction.

Historical summary of GCM development (1956-90)

As already stated GCMs are very important tools for understanding the climate problem. Efforts in this direction started in 1956 when only modest computer power

was available. With the tremendous enhancement of computer power now available with the atmospheric science community, highly sophisticated models have been used and we are almost on the threshold of a new era when short-term climate variability predictions would be possible by the turn of the century. The major events that have occurred in climate-related modelling effort in the last 35 years are listed below.

Progress

- First atmospheric GCM (channel model of mid-latitudes with geostrophic flow): 1956
- GCM (primitive equations) winter and summer circulations (GFDL Group): 1963-1970
- Predictability studies with GCMs: (1970-1980)
- Doubling of carbon dioxide climate scenario: (1970-1990)
- Sensitivity studies with GCMs and formation of more groups on climate models. About 20 groups function today
- Report of the JSC study conference on climate models: 1978
- JSC/CAS working group on numerical experimentation (WGNE): 1985
- Workshop on systematic errors in models of atmosphere: 1988
- TOGA numerical experimentation group (TOGANEG): 1986
- TOGA monsoon numerical experimentation group (TOGA MONEG Intercomparison): 1988-91
- IPCC Report: 1990
- Intercomparison of climate simulated by 14 AGCMS: 1991
- US NMC climate data assimilation system: 1991
- Ten-year analysis project: 1991-92
- Programme for climate modelling diagnosis and intercomparison (10-year) simulations: 1991-92

Modelling groups working in U.K.

- UK Meteorological Office (Hadley Centre for Climate Research)
- UK Universities Global Atmospheric Modelling Project

Modelling groups working in India

- Emerging at a few organizations such as IMD, IITM, IIT, IISc and NCMRWF

Climate models group

A variety of climate models, differing in horizontal and vertical resolutions and physical parameterization schemes, are available now. Recently, the results of these

models were compared (WMO 1991). The groups which participated in this effort are listed below:

Group		**Horizontal resolution**	**Vertical resolution**
BMRC	Bureau of Meteorology Research Centre, Melbourne, Australia	R15 R31	9 9
CCC	Canadian Climate Centre, Downview, Canada	T21 T32	10 10
CNRM	Centre National de Researches Meteorologigues, Toulouse, France	T42	20
ECMWF	European Centre for Medium Range Weather Forecasting, Reading, UK	T42	19
ECHAM	Universitat Hamburg/MPI Hamburg, Germany	T21	19
GFDL	Geophysical Fluid Dynamics Laboratory, Princeton, USA	R15	9
LLN/OSU	Lawrence Livermore National Laboratory/Oregon State University, USA	5°xt°	2
LMD	Laboratories de Meteorologie Dynamique, Paris, France	7.5°x5°	11
MGO	Main Geophysical Observatory Leningrad, USSR	T21	9
MRI	Meteorological Research Institute Ibaraki, Japan	5°x4°	5
NCAR	National Center for Atmospheric Modelling Project, Boulder, USA	R15 T42	12 12
UGAMP	UK Universities Global Atmospheric Modelling Project, Reading, UK	T21 T42 T106	19 19 19
UKMO	Meteorological Office Bracknell, UK	3.7°x2.5°	11
UM	University of Melbourne, Australia	R21	9

Figure 6, taken from the WMO report shows the scatter in June, July, August zonally averaged precipitation provided by simulations by different models. The scatters indicate the uncertainty involved in simulating precipitation by these models.

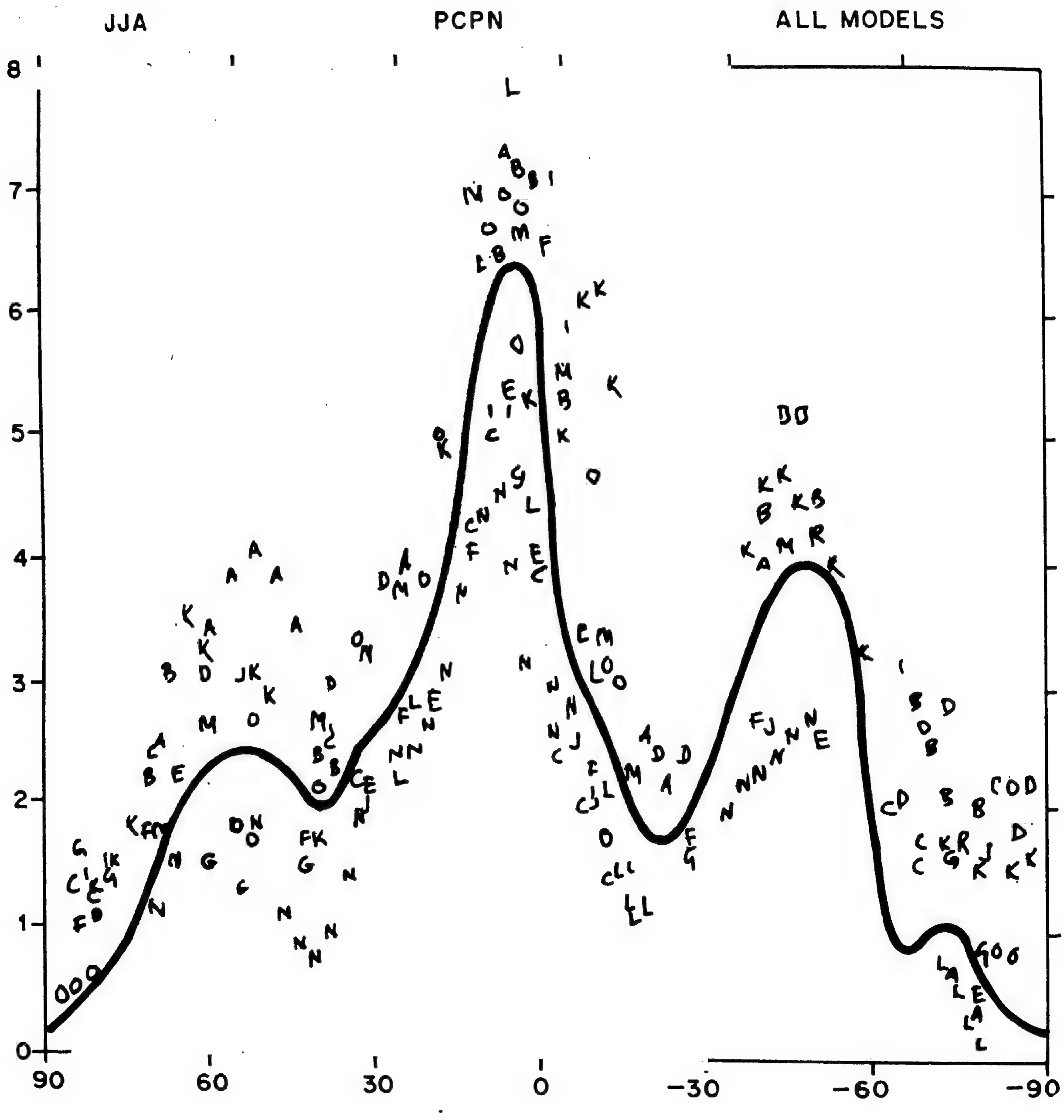

Figure 6. Scatter in June, July, August zonally averaged precipitation provided by simulations by different models (WMO 1991).

International climate modelling/prediction projects
Ten year analysis project (global change) 1979-89.

Major developments in climate change awareness among the atmospheric scientist community

Concern for the change started in 1960 and this has been intensified during the last decade. Major efforts on the international and national level in India are listed below.

International

Concern for climate became prominent since 1960. Intensified concern in the last decade is reflected from the following efforts/events:

• World Climate Conference (WMO, UNEP)	1979
• World Climate Programme	1979
• International Geosphere Biosphere Programme Our Planet Earth Programme	1985 onwards
• Intergovernmental Panel on Climate Change	1988
• Second World Climate Conference Co-sponsored by WMO, UNEP, Unesco, IOC, FAO, ICSU (747 participants from 116 countries took part)	1990
• WMO special fund for climate and atmospheric environment studies	1990
• United Nations Conference on Environment and Development (Brazil)	1992

India

• Concern about monsoon failures	1956-1974
• Planning Commission interest and establishment of Drought Research Centre in IMD	1973-1980
• Monsoon—El-Nino relationship suggested and further work continuing	1980 to date
• Indian National Science Academy (INSA) forms a Committee on Climate Research	1980
• Monsoon Rainfall and Temperature series for India	1980 onwards
• Involvement of the DST (Department of Science and Technology) in TOGA, of DOD (Department of Ocean Development) in WOCE, Department of Environment in climate change, Several science departments in IGBP and climate change	1986 onwards

- Establishment of NCMRWF with supercomputing facility 1989
- Proposal for a Monsoon Sections (MONSEC) programme 1991
- Proposal for a land-surface-process experiment over western India 1992

Current international programmes on climate-related work

- World Climate Programme (WCP) (Climate and computer, climate data programme, climate applications programme)
- World Climate Research Programme (WCRP, TOGA, WOCE, ISCCP, ISLCP etc.)
- World Climate Impact Studies Programme (WCIP)
- Global Energy and Water Cycle Experiment (GEWEX)
- United Nations Environment Programme (UNEP)
- Joint Global Ocean Flux Study (JGOFS)
- Climate Change Detection Project (CCDP)
- Past Global Changes (PAGES)
- Earth Radiation Budget Experiment (ERBE)
- Geophysical Monitoring of Climate Change (GMCC)

India is participating in all these programmes. Besides, some process studies on a regional scale are planned for execution by Indian scientists. A programme on the Monsoon Trough Boundary Layer Experiment was conducted in 1990. Two other multi-year programmes, namely land-surface processes for weather and climate over western India and MONSEC, are contemplated for the next decade.

Observational programmes contributing to/planned for climate monitoring and prediction

- World Weather Watch (WWW)
- Global Atmosphere Watch (GAW)
- Global Climate Observing System (GCOS)
- Global Earth Observing System (GEOS)
- Integrated Global Ocean Services System (IGOSS)
- Integrated Global Ocean Surveillance System (IGOSS)
- Global Ocean Observing System (GOOS)
- Global Sea Level Observing System (GLOSS)
- Background Air Pollution Monitoring Network (BAPMON)
- Global Ozone Observing System (GO_3OS)

India is a partner in most of these programmes.

Satellite missions relevant to climate monitoring

Dedicated space-based observational systems are very crucial for climate and weather monitoring on global and regional scales. The operational and planned missions are listed below.

Operational satellites

Missions	**Country**
NOAA polar orbiting series	USA
METEOR polar orbiting series	Russia
Geostationary series	USA, European Community, Japan, and India
Earth resources series (Landsat, SPOT, ERS, IRS etc.)	USA, European community, France, and India
Ocean observing series (TOPEX/Poseidon)	USA, and France

Continuance of these satellites is crucial to climate monitoring and prediction efforts.

Proposed satellite missions

Tropical rainfall measurement mission including lightning imaging sensor	USA and Japan
Improved versions of ocean satellites (1993 onwards)	USA and France
Earth observing system satellites (1997 onwards)	USA, Europe, and Japan

Some recommended sensors for Earth observing system programme (USA, Europe, UK, France, Canada) 1997-2001 and beyond

Solar irradiance monitor, advanced IR sounder, AMSU, advanced thermal emission and reflection radiometer, cloud and earth radiant energy system, high resolution dynamic limb sounder, microwave humidity sounder, spectrometers, measurement of pollution in the troposphere, scatterometer, SAGE altimeter, laser atmospheric wind sounder, SAR tropospheric, and emission spectrometer.

The recommended instruments will study:

- Clouds, radiation, water vapour, and precipitation
- Oceanic productivity, circulation, and air-sea exchange sources and sinks of greenhouse gases
- Changes in land use, land cover, primary productivity, and water cycle

Prominent climate data centres and systems

Past climatological data are very essential for undertaking observational studies on climate and allied subjects. The atmospheric science community has organized dedicated international and national data centres which archive and distribute data to different users. Some of the major data centres are listed below:

- World Data Centre (WDC), USA and Russia
- Comprehensive Ocean-Atmosphere Data Sets (COADS), Boulder, USA
- Tropical Ocean Global Atmosphere (TOGA) Data Centres (in different countries; India has also sponsored a Centre on Tropical Upper Air Winds).
- Global run-off Data Project
- Global Precipitation Climatology Data Project
- Global Telecommunication System
- Global Data Processing System (GDPS)
- Geographic Information System (GIS)
- Global Resource Information Database (GRID)
- National Climate Data Centres (in different countries; the Indian centre is located at the India Meteorological Department, Pune)
- Data Centres for special WCRP Programmes
- Meteorological Satellite Data Centres

Also, countries such as USA, Japan, and Australia are providing a variety of climate diagnostic information on a monthly basis, based on processing of operational data.

Agencies involved in climate-related matters

Several international and national agencies are involved in climate-related matters:

International

- United Nations and its special agencies (WMO, UNEP, FAO, Unesco and IOC, UNDP, WHO, UNIDO)
- Intergovernmental organizations (ICSU, IOC, IPCC, CCCO)
- Scientific Committee on Problems of Environment (SCOPE)
- Scientific Committee on Ocean Research (SCOR)
- Non-governmental organizations (over 50 in number)

National (Indian)

India Meteorological Department, NCMRWF, INSA, IITM, Indian Institutes of Technology, Indian Institute of Science, universities.

Global climate observing system: scope and perspective

For the work relating to climate monitoring and prediction a specially dedicated observing system has been conceived under the auspices of the WMO. Salient features of this system are described below:

Goals

- Climate system monitoring, climate change detection and response.
- Data for applications in national development
- Data for research towards improved understanding, modelling and prediction of climate system, comprehensive observational system for climate forecasting
- Observations on parameters of a wide range of atmospheric, land surface, surface and deep ocean properties, global coverage, continuous observations on decadal time scales about characteristic thermodynamic, dynamic, geophysical and biogeochemical processes of the climate system

Steps needed

- Continuation of WWW
- Establishment of GOOS, continuation of WCRP, IGBP, GEWEX, and other programmes
- Maintenance and continuous development of space-based technologies, global precipitation climatology project, global run-off data centre, national and world data centres, climate modelling, analysis and prediction projects
- Systems of study needed on:
  Atmosphere (standard meteorological including precipitation, radiation and cloud measurements), chemical composition of atmosphere, land-surface parameters, biogeochemical dynamics, ecological system dynamics, earth system history (abrupt climate change, geological records of global change)

5. Summary

The article has emphasized the following aspects:

State of knowledge

- Climate has shaped our lives, national resources, and economy and will continue to do so in future
- Monsoon climate, on the thousands of years scale, has changed and the country has witnessed wet and dry epochs due to glacial and inter-glacial phases
- Data on monsoon rainfall recorded from meteorological instruments have been extended by Indian workers to 1813 and a study of these records show that inter-annual variability is an important feature of the monsoon

rainfall. On the decadal scale the monsoon rainfall is very stable and the inter-decadal variability is rather small. Though two or three bad monsoon years may occur in a particular decade, overall the monsoon is expected to perform close to normal. This stability of the monsoon rains on the decadal scale is an important asset for long-term planning needs

- Scenarios based on analogue data and climate change due to doubling of CO_2 using GCMs suggest that most of India would be wetter by 10 to 30% during the summer. There are, however, considerable uncertainties in building up regional climate estimates based on GCM experiments.
- We are ourselves modifying the atmospheric constituents and therefore the pace of climatic change may be rapid. We need not be helpless witness to the flow of events
- The world faces a threat, potentially more catastrophic than any other in human history, in regard to climate change and global warming. Awareness of the threat has begun to filter into the public domain. It has been at the forefront of concern for the international scientific community for three decades now
- We do not wish to go back on the path of development. Indeed we cannot go back
- Climate system responds slowly; currently observed change may be hidden and the impact cannot be assessed in quantitative terms as yet
- Predictions of future temperature rise and likely climate change such as rainfall change are based on current computer models that cannot take into account many of the interactions within the complex network of systems that make up the dynamics of our planet
- Scientists have contributions to make in the following aspects:
  (1) To predict as accurately as possible how the climate will change
  (2) To identify the uncertainties so as to quantify the risks
  (3) To provide a basis for risk management due to climate change
  (4) To help identify policies which are desirable and tend to reduce future effects

Requirements for future

- Maintenance and improvement of WWW and GAW observational systems
- Enhancement of space-based and surface-based instruments for monitoring atmospheric constituents, clouds, radiation budget of the earth, precipitation, winds, SST, and terrestrial ecosystem
- Establishment of global ocean observing system to measure changes in surface topography, circulation, transport of heat and chemicals, and the extent and thickness of sea ice

- Use of paleo-climatological and historical instrument records to document natural variability and changes in the climate system and subsequent environmental response
- A global atmosphere-ocean-land climate data analysis and prediction component based on one or several dedicated facilities
- A research component to address outstanding problems

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PANEL DISCUSSION

Session 1
Science

Dr Lal (Indian Institute of Technology, New Delhi)

My first observation is on the paper on dynamics of heat transfer in the ocean. On such a subject a little more precision is always possible. It was mentioned that carbon dioxide is absorbed in the colder northern waters and is released out in the warmer southern waters. Though we refer to carbon dioxide and cumulative increases in its concentrations, it is really made up of two molecules or two species, $C_{12}O_2$ and $C_{13}O_2$, two stable lateral isotopes, the relative abundance of the latter being about 1.1% of the former. They are identical in terms of their physical properties but their heat capacities are different. Strong bands in the infrared part of the spectrum account for their ability to act as a heat trap. The 2350 and the 6731 in $C_{12}O_2$ gets significantly shifted in $C_{13}O_2$ and their solubilities in water are different. In such a system, a very small incremental change can cross the threshold value. Is there a change in the composition of carbon dioxide between $C_{12}O_2$ and $C_{13}O_2$ in different areas of the atmosphere and ocean water system relative to their solubility? If so, is there is a change in the relative concentrations? And does it make a difference when we are considering very small incremental temperature changes? That was the point which I wanted to raise.

The second observation on Dr Sikka's paper relates to the importance of a database. We should also take folklore into account. Folklore says that it is not just a warm summer but a warm summer *and* a cold winter that gives us a good monsoon: a cold winter (especially a cold and wet winter) leads to thicker ice caps on the Himalayas, which melt during a warm summer leading to a good monsoon. Folklore, tradition, and even mythology, provide important data and wise leads when it comes to climate change over a period of thousands of years.

Dr Sikka

We include what is available in scriptures and in the folklore. However, we have to validate it if it is to be used. Folklore yields data that are highly localized; on

the subcontinental scale its importance is accordingly reduced. If the folklore is based on a physical process such as the one you mentioned it can be one of the predictors. We have data about the Himalayan snow cover for a few hundred years and it is one of the predictors. But, because the data are obtained from different sources, it is not such a highly reliable predictor. All the same, we still retain it as one of our predicting parameters. More reliable than the Himalayan snow cover is what we now call the Eurasian snow cover. Satellite measurements of the Eurasian snow cover has made available 25-year data. The data also indicate that by and large it is a factor to be considered, though it cannot be the only one. There are years when the so-called Himalayan snow cover or the Eurasian snow cover was much more, but still the monsoon performed very well in spite of that. So these are factors that have to be considered and then validated by means of numerical modelling. At the Max Planck Institute, a model included snow cover as a boundary condition, which could be changed easily. The thickness could be doubled, for instance. When the model was run, the monsoon performed poorly when the snow cover was more but the folklore says exactly the opposite. Also, physical considerations show that if the snow is more, more incoming energy would be used in melting the snow first before it heats up the system.

Dr Agni

At the Max Planck Institute, experiments spanned a 100-year period, from 1985 up to 2085. This experiment was based on IPCC Scenario A ('business as usual') and D ('stringent policy'), and a doubling of CO_2. I had the opportunity to study the impact of global warming on the monsoon climate. Briefly, an atmospheric model from the European Centre for Medium Range Weather Forecasts, was been adapted for climate simulation. It includes 19 layers in the atmosphere. The ocean model, which is coupled to the atmospheric model, is a large-scale geostrophic ocean model at a T21 resolution. So we have 64 grid points in the longitude and 32 grid points in the latitude i.e. a latitude-longitude interval 600 km. Within this limitation, we have an 8 × 8 grid over the Indian region of very poor resolution. I wanted to use the data output from these experiments to investigate the impact on the climate over the Indian region. To validate the model for the monsoon region, we compared the model output from the controlled experiment for the first ten years with mainly the actual observations. We found that the model had a high [?] scale in simulating the actual monsoon climate over the Indian region, based on the June to September period. We also looked at the daily rainfall data simulated by the model. We found that the variability in the 100-year run simulated by the model was very much similar to the recorded variability in the date of onset of monsoon over Bombay. We also looked at the Scenario A run to see whether greenhouse warming could have any impact on the onset of monsoon. The impact was not significant; it differed by only

one day: instead of 10 June it was 11 June. Then we looked at the area average. In Scenario A we found that it is about 2.2°C compared to the global mean of about 2.6° C. So there is no substantial change from the global mean in the case of warming. As to precipitation, in Scenario A the precipitation increases by about 7 mm per month. The evaporation is about 0.5 mm per month. The results indicate that most changes likely to occur in 100 years are within the internal variability of the parameters in the monsoon season, except temperature. We wanted to see whether there is any clear signal of warming in the monsoon region. In Scenario A, there is a clear-cut signal of temperature increase as compared to Scenario D. When this was done for precipitation, we saw that the internal variability was so much that there was no clear-cut signal for Scenario A run as compared to the control run. The same holds good for convective precipitation too. The signal is not very clear in the 100-year experiment. We see maximum warming over Pakistan and Afghanistan, over India it is somewhere between 2 and 2.7° C warming.

There is an increase in precipitation over the central plains and a slight decrease over the southern peninsula. Evaporation will increase throughout the country. Soil is deficient in moisture over nearly the whole of southern India. So the conclusion is that any change in 100 years is going to be within the internal variability. This is a preliminary study we have got the data now, but a lot is to be examined as yet.

Dr A K Bhattacharya (Jawaharlal Nehru University)

My comment is on the soil moisture reading. It could certainly affect the total productivity because temperature, moisture and the biological responses are interconnected.

Mr S K Gupta (Physical Research Laboratories, Ahmedabad)

It may be pertinent if we can devise a system to detect the sea level rise more quickly. If sea level rise is monitored by monitoring the fresh water--sea water interface in suitably located tubewells on a relatively quiet island, it could magnify the signal of sea level rise approximately 40 times. This is because of changes in the density of sea water and fresh water. There are problems since the two liquids are not totally immiscible and also because the interface is not a sharply defined line but exists as a zone. But one should be able to devise a system to measure sea level rise this way.

Mr David Pugh

We have no problems measuring sea levels, and there is no particular advantage in measuring it indirectly by intrusion into estuaries. Our problem is actually to remove real variables such as year-to-year circulation changes and wind stress effects from

measurements. If we can get rid of these changes by understanding the circulation of the Continental Shelf and the circulation of the ocean, we might be able to see the trends earlier. The problem is not of measuring sea level; it is of removing the noise, as I call it, to see the long-term trend.

Dr D P Agarwal (Physical Research Laboratories, Ahmedabad)
I would like to emphazise the importance of the continental recurs. So far, we have had long recurs from the sea, the Arctic, ice cores, etc. but if you want a higher resolution, both spatial and temporal, the continental recurs may prove better. For example, 125 000 years ago we had very high carbon dioxide levels, almost as much as we have today, and also very high temperature recurs. Then these went down and rose again. Some reservoirs may become sinks and sources in different periods under different conditions. This sort of data would prove very important.

The other point in the context of the Indian situation is that now we have normal recurs but they are all qualitative. We have been using mineral mandative recurs, pollen recurs, and organic markers of climatic change, but most of them are qualitative. An effort has to be made to quantify them. Only then is some modelling possible, which is absolutely essential. These continental recurs need to be properly studied. We have to develop these techniques further so that we can take and generate quantitative proxy climatic data.

Member of the Audience
The modelling community has realized that models nave their uncertainties. A major project is being launched at the Lawrence Livermore Laboratory in the US that will involve a 10-year simulation: not a one or two year scenario but a 10-year simulation by a number of groups. Fourteen groups have already joined and more groups are likely to follow. This project will also re-analyse actual climatic observations over a ten-year period (1978-89). These models are very good; they are robust, but there is a variability among them which has to be narrowed down in the next decade.

Dr Yajnik
In the prediction of climate uncertainties have a different role because what we are trying to predict is completely different from the classical weather prediction problem. There is certainly an evolution, but the uncertainties that I was referring to were of a different kind. These uncertainties come about because, for examples, some of the feedbacks are not put into the model. It is not the uncertainties arising from the data or the mathematical method or the method of discretization used or anything like that.

Dr Jenkins

I would support the point that we are talking about a different type of determination or a different type of predictability where we are looking for changes in mean values rather than looking at it in terms of dependability or dependence on the initial value. What we are looking at is something that depends on the boundary conditions. There are certain tests of the models in terms of their ability to look at present day climate values. It is very encouraging that already some of the models are able to predict these. We use them also for looking at seasonal forecasting. To a certain extent they can be quite good predictors of, for instance, rainfall over a given region. It is not just the question of models being good at simulating today's climate, but also the variability of today's climate that gives hope that they will be able to predict future climates.

Mr O P Sharma (Indian Institute of Technology, New Delhi)

In the ocean, we have warm currents and cold currents. Could we find some new currents while simulating the ocean's circulation? For example, while addressing the problem of distribution of heat by the oceans, do we see more number of warm currents? Secondly, the differences in measurements found over the Atlantic as compared to other regions. (I refer to one of the graphs which you have shown). Was it purely for a modelling purpose, or do you expect some phenomena to be discovered there so that you require a fine scale for investigation and observation? Specifically, the grid points are very fine over the South Atlantic, near South Africa, the Falkland Islands, etc. But over the Indian Ocean, for example, there are just straight lines and not that fine.

Dr Pugh

The distribution is based largely on the variability and space of the oceans. I am not sure whether the possibilities of making measurements in the Indian Ocean were taken into account. But I would say that in the World Ocean Circulation and Experiment, apart from the global survey, there are special studies/core programmes, one of which relates to the southern ocean and the other which relates to eddy generation and propagation in the North Atlantic which is also taken into account.

Mr Sharma

While simulating the ocean circulation, we change the scenario and see how it is affected. Do we see any new currents that are persistent in nature? For example, when there is a global warming, some of the heat will be distributed by the oceans. In such a case, do we see more warm currents?

Dr Jenkins

There have been suggestions that, potentialy, very large changes to occur; for instance, an automatic drift brought about by changes in global climates. In fact, some of the previous climate records can be interpreted in terms of that sort of effect. However they are purely indicative of the potential.

Dr Pugh

There is also the question of vertical mixing and the possibility, at least in the North Atlantic, that the downward movemement of water might be inhibited if we were to form a fresh layer at the surface. And that might have quite an influence on the exchange of heat. So there are indications that we cannot assume that everything will stay as it is.

Member of the Audience

The subject of ozone depletion has been discussed in the industrialized nations and debated very widely. Regretfully, in this region it has not been talked about much. I remember that as a young man, after doing a spell of about three weeks or so in submarines we used to be given special leave to be able to recoup our health. With the development of science, submarines can now stay out much longer than before. In fact, Polaris can stay out for years. How does this affect our health?. How would it affect plants and animals?

Dr Farman

I can merely repeat a couple of secondhand opinions for you. One maintains that the damage to plants and organisms is roughly linear with the amount of UVB (ultraviolet - B) falling on them; one really cannot say very much more than that. But there are other possibilities such as the threshold effect and these are the most worrying. There are also the ones that we know the least about. If you followed the debate, for example, on melanoma five years ago, UVB radiation was scarcely recognized as anything other than a part cause of melanoma. Now we are informed that melanoma can enter our system at the age of ten or twelve; it lies latent and then develops in some part of the body. It is a sort of chemical change that is transmitted within a body and emerges twenty or thirty years later. That is one of the horror sides of the story. No one knows the real answer.

Member of the Audience

Ultraviolet rays have shorter wavelength and greater amount of energy. But green plants cannot use these rays for photosynthesis. Therefore, when the UV rays increase, photosynthetic activity is likely to decrease and as a result of which plants will be affected. Moreover, UV rays are believed to be mutagenic. All along the equatorial

belt, where the solar rays are not filtered out properly, the negroes have a pigmented skin; they absorb more UV rays but are very well protected. So UV rays can be taken care of by the atmosphere if the atmosphere is intact.

Member of the Audience
Does climate change occur in steps? Or is it a gradual process?

Dr Jenkins
Steps is perhaps the wrong way of looking at it. Superimposed on a gradual increase (surface temperature, for example), which would be linear or at least gradual or monotonic, there will be other factors. If the monotonic increases are due to man-made greenhouse gases, there will be other factors that will perturb the records. Natural variability is probably the biggest and of the order of 0.3° C. On top of that you have volcanic effects. It has been estimated that volcanic eruptions in Mount Pinatubo may lead to a lowering of surface temperatures by perhaps up to 0.5° C or so, which is a very big signal. There are the natural effects like El Nino which of course lead to a warming. We think El Nino has started already and may be increasing. Other factors include solar variability; though not dominant, it can certainly influence the record. So the underlying trend would be fairly monotonic but with other factors superimposed. It means that we do not expect the warming to be gradual or monotonic because other factors will lead to troughs and peaks during the course of that trend.

Dr Sanjeeva Rai (Centre for Research on New International Economic Order, Madras)
Methane is said to be one of the greenhouse gases, and India is said to contribute quite a lot of methane through its paddies and cattle. But rice is the staple food in large parts of India. Can we really get rid of the paddies and the cattle? If not, how can we reduce this methane production?

Dr Jenkins
It would not be easy to reduce methane production from agricultural sources at all. I do not think it is one of the targets, although I believe some work is being done on the strains of rice and the ways of feeding animals to reduce methane emissions. The easier target would be to look at fossil fuel emissions of methane as something that can be controlled more easily.

Dr Jayshree Devi Sharma (Jawaharlal Nehru University, New Delhi)
Perhaps the single most direct cause of ozone depletion is chemical changes in the atmosphere. This compounds the indirect effects as seen with solar radiation and changes in pressure leading to the ozone hole as shown. The aim can therefore be

to find antagonists to CFCs rather than substitutes like hydrofluorocarbons. New technologies that utilize such antagonists will reverse more rapidly the processes of chemical accumulations that led to ozone depletion and will fill up the holes. Would you advocate the use of such antagonistic technologies instead of waiting for the CFCs to slowly wear off? Would you prefer a quicker cure or wait and buy time? Your choice would obviously reflect the true urgency of a crisis called ozone depletion with its overtones in the Montreal Protocol and arbitration between countries.

Dr Farman

There are technical fixes but when you look at them coldly you realize they are much worse than the problem. Ozone is the residue, it is the balance between the amount created and the amount destroyed. If we want to create more ozone we simply have to provide a known amount of energy. The energy to cure the Antarctic ozone hole is the power supply of the United States. It is just that you need an awful lot of explosives or rocket power to put it up where it is needed. Let us be clear of one thing. We do not want that amount of ozone near the ground —it is toxic and and will harm vegetation. We do not particularly want it in the upper troposphere since it is a very powerful greenhouse gas there. If we are going to consider this then we have got to put it back where it is being destroyed. And of course the answer from the global warming point of view is we simply cannot afford to waste that amount of power by trying to attack the ozone problem.

What about trying to get rid of the CFCs? Again, it is easy in principle. You make an ultraviolet laser; you shine it up into the sky; and you try and hit a CFC molecule—shatter it to bits and get it out of there quickly. Now you do the sums again. How much CFC is there? It is a part of a billion. I do not know if you have thought about what a part of a billion means but it is really quite straightforward. Take a 1000 km—from here to the north of the Himalayas, something of that sort that is a million metres. Now we want one part of a billion. We are looking for a millimetre in a thousand kilometres. That is our chance of hitting the target —it is very much easier to stop putting these things into the atmosphere. I am not saying there are no technical fixes—there may well be a technical fix—but every one we have thought of so far turns out to be sillier than the problem. It is easy to prove that something is dangerous: you just do one simple test; if it is harmful, it is dangerous. But how can you prove that anything is safe? It means you are so clever and you have thought of everything. There are no such people about. No, let us not try engineering in the atmosphere; not within the forseeable future at least.

Impact of climate changes on forestry

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Our climate arises from the interaction of solar radiation and the atmospheric blanket that surrounds the Earth. From the atmosphere come oxygen, carbon dioxide required for photosynthesis, and moisture needed by trees, the sum total of which is climate. However, the climate in which a forest stand lives may be entirely different from the regional or macro-climate and is generally referred to as micro-climate, i.e. the climate near the ground, surrounding the tree, or affecting a critical part of the tree. The climate is characterized by certain meteorological elements comprising temperature, humidity, precipitation, sunshine, and winds and their variation with time. Different levels of these factors react differently with forests. Each element of climate qualifies and adjusts the interactions between the climatic elements and the life processes of forest species.

Climate exerts profound control over photosynthetic rates (Zelitch 1975, Govindjee 1975). In addition to the obvious importance of solar radiation and ambient carbon dioxide (Anderson 1973), moisture, temperature, and nutrition are critically important environmental variables. Water deficit decreases photosynthetic CO_2 uptake by restricting the transport of this gas to the chloroplast in both the gaseous and liquid phases. Carbon dioxide uptake generally increases with increasing temperatures to some maximum and then decreases. Low temperature, chilling, and frost stress reduce photosynthetic rates (Bauer et al. 1973).

Since the growth of trees is obviously closely related to their rate of photosynthesis and the rate of photosynthesis can be measured by measuring the uptake of CO_2 from the air by the plants, there have been many studies on the effect of varying amount of light upon the rate of photosynthesis. At very low irradiance level photosynthesis takes place at such a slow rate that it fails to utilize all the CO_2 given out by the plants during respiration. Under such conditions, the amount of CO_2 actually given off by the plants exceeds that being absorbed by them from the atmosphere. For forest trees under otherwise optimal conditions the point

where, during photosynthesis, CO_2 is neither given off nor taken up, appears to occur at 1 to 2 % of full sunlight. In very dense forest, net photosynthesis occurs only when the leaves are bathed in sun-flecks, but many understorey species of dense deciduous forests make net gain in growth when the trees in the upper stories are leafless.

Plant parts generally function in the tissue temperature range of 0 to 50 °C if living cells and protein compounds are biologically stable and enzymatically active. However, with change of season, foliage becomes conditioned and functions well at temperatures associated with the season. In forest trees photosynthesis takes place at air temperatures below freezing, down to about −8 °C, although at such temperatures tissues are usually warmed to near or above the freezing point by solar and terrestrial radiation. Though low temperature reduces the rate of photosynthesis, appreciable photosynthesis in conifers takes place in winter.

As temperature increases, plant activity enhances up to an optimum temperature rise after which it decreases until, at very high temperature, death may occur. In plants, temperature influences (1) the activity of enzymes that catalyse biochemical reactions during photosynthesis and respiration, (2) solubility of CO_2 in plant cells, (3) transpiration, (4) ability of roots to absorb water and minerals from the soil, and (5) membrane permeability.

Temperatures above 50 °C are largely confined in forested regions to the ground-air boundary. Direct heat injury in forest trees is most significant at seedling stage because of relatively unprotected live tissues in the critical zone. However, leaves of many mature hardwoods and conifers suffer damage due to water deficiency in cells, particularly along leaf margins and tips of the needles. Widespread leaf damage to forest species occurred in northern California when temperatures suddenly rose above 39 °C in areas that had an exceptionally cool spring (Treshow 1970).

However, unlike lethal high temperatures, lethal cold temperatures occur only periodically during the tree growth in the temperate and boreal regions of the earth. Most trees in these zones become increasingly inactive as the day shortens and temperatures drop at the end of growing seasons. Death of plant tissues, particularly of actively growing succulent tissues, may occur from rapid freezing and formation of ice crystals within the protoplasm.

Global forest ecosystems and climatic constraints

There are two ways in which ecosystems can possibly be affected by the rising levels of greenhouse gases, and they are not necessarily mutually exclusive. The first is the direct effect of higher ambient carbon dioxide concentrations on plant growth and development.

Overall, experimental research consistently demonstrates that, directly, CO_2 is potentially beneficial in terms of crop yields and possibly forest productivity. In

general, higher ambient CO_2 stimulates greater net photosynthesis—the so-called 'fertilization' effect, and decreases transpiration through a partial stomatal closure, resulting in greater water use efficiency in plants, at least at the micro-scale.

The second way in which ecosystems can be affected by increasing concentrations of greenhouse gases is through changes in climate. Here too, uncertainty abounds in relation to the changes in regional climate, their effects on plants and ecosystems, and the ways in which enhanced carbon dioxide will modify the effects of climate on plants. The extent of our knowledge concerning changes in climate can only be expressed confidently in terms of averages on the global scale.

The relatively 'natural' appearance of many forested landscapes can give one the false impression that forest ecosystems are largely unmanaged. In fact, the world's forests are subjected to a wide range of management from intensive commercial extraction to extensive resource conservation. Therefore, as in agriculture, the potential impact of increasing concentrations of atmospheric CO_2 and climatic change must ultimately be examined in the context of human use and manipulation of the natural system.

In the most extreme case, there has been some experimentation with intensively managed biomass plantations in which trees are irrigated, fertilized, and harvested in short (2 to 5 years) rotations. This form of cellulose production is the type of forestry that most closely resembles intensive agriculture. Forest management involves the regeneration of commercially valuable trees species by altering site conditions, planting seedling trees at appropriate spacing, thinning the trees, and harvesting the tree crop. In a favourable environment, some of these activities are left to natural processes. For example, if a commercial tree species has vigorous regeneration in a given environment, the steps for site preparation or planting are automatically taken care of, and thinning and harvesting of trees remain the only major concerns. In less intensive forestry, trees are periodically harvested, but the thinning of trees to optimize the forest productivity is omitted. In extensive forms of management, forests are maintained to protect watersheds, wildlife habitats, or recreational environments. Even in the remotest forests, there is a degree of management that stems from human intervention with natural processes, for example, reducing the frequency of wildfires in wilderness areas.

Because of this gradient of management intensity, global environmental change could manifest itself in radically different ways. In more intensive forms of forestry, a change in growth and regeneration rates could affect management costs or the techniques used to extract wood products. In the less intensively managed forests, environmental changes might actually change the structure, composition, and areal distribution and consequently the function of the forest ecosystem.

There are two aspects of the behaviour of forest systems that should be considered in assessing the impacts of environmental change. First, there is a

considerable degree of spatial heterogeneity in the potential response of the world's forests to changes in climate, as discussed above. Second, at any given place there is a wide range of temporal scales over which forests will respond dynamically. Unlike the vast majority of agricultural systems, forested systems are dominated by long-lived organisms (trees) that can respond to stress or change at several different time scales. Problems in assessing the response of forest systems with respect to any alteration of environmental conditions are made complex by these multi-level responses.

Ecologist George Woodwell suggests that rising temperatures from the build-up of CO_2 and other greenhouse gases could substantially increase the respiration rates of trees and soil microorganisms, especially in the middle to higher latitudes where the temperature rise will be most pronounced. When respiration outpaces photosynthesis, trees release more carbon dioxide to the atmosphere than they remove, as those of deciduous character do during autumn and winter when they lose their leaves. A temperature-induced increase in respiration could cause a significant additional release of CO_2, reinforcing the very build-up that initiates the warming.

Indeed, ecologists do not yet agree on how forests will respond to climate changes, or even on whether that response will absorb or release more CO_2 to the atmosphere. Another possibility, for example, is that higher temperatures would increase rates of organic decomposition, which in turn would release nutrients to the soil and thus potentially boost the productivity of trees. Since trees would then be growing fast, they would remove more CO_2 from the atmosphere, thus mitigating or counteracting the phenomenon of warming. The uncertainty about the response of forests to the warming looms large since the potential for a strong feedback, positive or negative, clearly exists.

Climate change and the response of forests

The clearly observable correspondence between the distributions of global climates and the spatial patterns of vegetation leads one to expect that a change in the former should eventually produce a response in the latter. Climate factors that should be considered in evaluating the potential change in a real distribution of the world's forests have been investigated by some scientists.

Guidance is provided by Holdridge (1964, 1974), who developed a systematic classification of the expected vegetation under differing temperatures and moisture conditions. The Holdridge diagram is similar to other climate/vegetation mapping systems in that it explicitly recognizes the variables of temperature (expressed in this case as 'bio-temperature' which is computed as a heat index for periods during which plants can be photosynthetically active) and moisture (expressed as either rainfall or evapotranspiration). The Holdridge diagram illustrates several relationships that, while

perhaps oversimplifying the case, provide a perspective for understanding the response of global vegetation to climatic change. First, there is a parallel between the latitudinal zonation of the earth (boreal, tropical, etc.) and the zonation of vegetation at different altitudes on mountains (montane, alpine, etc.). Second, the responses to temperature and moisture or precipitation changes depend on relative, rather than absolute, changes. A small absolute increase in temperature could be expected to cause a large response in the ecosystems of the cooler climates of high altitudes or latitudes. Similarly, a small absolute increase in moisture could have a profound effect in arid regions. To cause a vegetational change of comparable magnitude in a wet, warm region, the environmental changes would need to be much greater.

The amount of time that might be required for the areal distribution of forests to respond to a change in global climate is largely a matter of conjecture. The time needed for trees to migrate a region can vary widely according to the species (e.g. from 25 metres per year in *Fraxinus ornus* to 2000 metres per year in *Acer* species; Huntley and Birks 1983). The ranges of many important tree taxa in both North America and Europe have been moving since the large alteration of the global vegetation pattern that accompanied the last glaciation and may still be moving.

In mangrove ecosystems the water temperature along the estuaries and coasts in India remains almost constant with negligible rise in the exposed inter-tidal regions during low tides, and no report is available on the effect of high or low temperature on the Indian mangroves. In the areas where water reaches only if the tide is exceptionally high, characterized by low rainfall, high atmospheric temperatures, and high rate of evaporation, plants are dwarfed because their growth is affected. This type of hypersalinity occurs in Rann of Kutch. In this semi-arid region, mangroves occur in patches with scrubby vegetation. Thus any reduction in rainfall affects productivity due to hypersalinity in higher tidal reaches. This phenomenon is more pronounced in low rainfall areas (Untawale 1987).

Local changes in forest composition

A closer inspection of the processes controlling the structure and composition of a forest reveals that the mechanisms that could be altered by climatic change are numerous and of great potential importance. Changes in climate could be expected to alter differentially the regeneration success and the growth and mortality rates of tree species. Alteration in the competitiveness of the various taxa is most likely to be manifested as a change in the forest composition. Changes in moisture conditions could alter fire probabilities and rates of wildfire spread. *Gigasipham macrosiphon* (Harms) Brenan, a rare or endangered species, is known only in four localities in Tanzania and Kenya. It is reported that this species has been affected in the long term by climatic changes decreasing the area of forests, but more recently

by forest clearings for settlement and cultivation. Warmer winters could decrease the mortality of overwintering insect pests and thus increase the likelihood or perhaps the intensity of insect outbreaks.

Insects are very sensitive to climatic factors. Any change in the climatic variables such as temperature, rainfall, humidity, wind, sunshine, light, etc. has a definite effect on the development of insects. The population of teak defoliator (*Hyblea puera*) in teak zone builds up to epidemic proportions during the hottest period of the year, namely from the last week of June to July, but gradually declines with the onset of monsoons; simultaneously, the population of skeletonizer (*Eutectona machaeralia*) increases and causes widespread defoliation during August to October (Beeson 1991). On the other hand, during the hottest period of May-June, the population of *Atteva fabriciella* decreases and this is possibly an adaptation to tide over the adverse period of summer months. The population of *A. fabriciella* remains endemic during the warmer months of the year and epidemics generally occur from December to February in Shiwaliks (Misra 1973). The population of 'sal' (*Shorea robusta*) heartwood borer is at its peak during the rainy season: it is more with more rainy days during the monsoon months but declines when there are late rains or no rains (Beeson 1941). Epidemics of deodar (*Cedrus deodara*) defoliator *Ectropis deodarae* in Lolab valley in Jammu and Kashmir during 1983-1984 are attributed to an unusual drought in the region from 1980-83 in which the natural regulating mechanism of the defoliator was completely wiped off resulting in epidemic of the pest in the following year, i.e. 1983-1984 (Singh et al., 1989). Populations of the poplar defoliators (*Pygaera cupreata* and *P. fulgurita*) start building up in July and reaches peak in September with favourable temperature and humidity. It has also been observed that the attack of chafer grubs in teak nurseries is more when the nurseries are in open places, i.e. in warmer locations rather than in shaded places.

Research carried out in the Doon valley indicates marked changes in the climatic pattern. About a century ago, temperatures in this valley were recorded to fluctuate between 29 °C (maximum) and 13 °C (minimum). The average highest maximum temperature during past 10 years was 40.7 °C and minimum was 0.7 °C as recorded the Forest Research Institutes' meteorological observatory. Temperatures in May 1988 were alarmingly high (44.5 °C)—an increase of 4.8 °C from the preceding year and 3.8 °C more than the average highest maximum temperature recorded in the past decade. Rainfall recorded in the valley shows a decreasing trend during the last 10 years—2083.7 mm in 1980 and 1572.3 mm in 1988.

In one Indian context, sal mortality may be linked with the climate changes occurring in the regions of sal and teak forests. Seth (1954) discussed the pattern of drought damage and pointed out that two definite cycles could be discerned. One was a long-term effect, climatic and ecological in origin, leading to gradual xerophytism and consequent annual mortality. This requires long term studies. The

other effect was a short-term one, depending upon sudden variations in local climatic factors, e.g. rainfall, leading to sudden mortality.

Teak (*Tectona grandis*), although extensively planted in comparatively dry regions of India, has been found to suffer badly in abnormal droughts but the damage is fatal especially in young plantations. According to Seth (1956), the secondary agents causing injury to teak are drought, frost, and wind, as was also reported in a study of the mortality of teak in Melghat forest (Joshi 1974).

In a mature forest, when evapotranspiration exceeds the precipitation due to the change in humidity, some of the trees die due to a lack of proper water balance. Such a situation has been observed in sal forests in Uttar Pradesh, especially in Ram Nagar and Haldwani forest division. Sal is a semi-evergreen angiospermic species and any shortage .of water in the soil affects the total output of the leaf canopy. Being an angiospermic species, sal regenerates xylem tissue (through which the sap flows) every year after the leaf fall, unlike conifers that translocate water through tracheids and therefore cannot tolerate the shortage of water in the soil.

Associated with the climatic change, anthropogenic pressures are also responsible for the drying of the sal. In a study made by the Forest Research Institute (Bisht 1989) on the regeneration of sal, it has been observed that when there is an opening in the canopy of the forest, establishment of sal becomes a problem. When larger openings are made in the forest, it favours the growth of the associated species and young sal sapling suffer heavy mortality due to competition for moisture, which is a constraint.

The openings in the forest increase the radiation load on the forest floor. Thereby, the total evapotranspiration from the forest stand increases and creates more xeric conditions. Under such circumstances the microbial activity responsible for the decomposition has been shown to increase. This increased nutrient concentration offers a relatively better opportunity to the other species to grow and establish and eliminates the sal from the stand.

The magnitude of these changes could, in some cases, be quite large, even with relatively small changes in climate. Moreover, these effects are apt to be case-specific; it is difficult to generalize across all forests. For instance, a warming in one region could produce increased forest productivity and dominance of a valuable commercial tree species, while the same warming in another region could increase physiological mortality, pest populations, or wildfire frequency and reduce the extent of commercial forest.

Impacts of forest productivity

The community of vegetation, which finally attains an apparent stability at a site, adopts to maximum substance utilization of the environmental resources and since the environment is chiefly conditioned by the operations of the factors of climate,

a close correlation always exists between the sum of these factors and the biological productivity of a site. The climate thus determines the energy reaching the ground surface, the amount of water available for life processes, the period during which the temperature relations, are favourable to growth, and the extent to which temperature regime favours maximum biological activity. The various factors of climate reflect not only the degree to which conditions are favourable but also the intensity of factors that retard or limit such activity. If other factors such as soil and physiography are optimum, the productivity potential of a site is capable of being expressed through the integrated effect of the climate factors. The estimation of site productivity by one of the indirect methods, namely climate, has been a subject of continuing interest in forestry research. The most recent and fruitful application of this approach is due to Paterson (1966) who proposed the following formula.

$$I = Tv \times P \times G \times E/Ta \times 12 \times 100$$

I is the CVP index, Tv is the mean temperature of the warmest month (in °C), Ta is the mean annual range of temperature between the coldest and the warmest month, P is the mean annual precipitation (in mm), G is the length of the growing season in months, and E is the 'evapotranspiration reducer', a factor based on latitude and giving the generalized total annual radiation received as per cent of that at the equator. The complete equation thus yields the relation between climate, vegetation, and productivity. The correlation between the CVP index and the maximum or ideal productivity for different regions of the world turns out to be a significant at 95% probability, the variance of the CVP index contributing to about 80% of the total variance for the ideal site class. The equation for calculating productivity is $Y = 5.2 \log X - 7.25$ where Y is the productivity in cubic metres per hectare and X is the CVP index.

The immediate responses that one might expect to occur from increased CO_2 or climatic change involve modifications in forest productivity. Again, there are numerous differences in productivity and in the factors that could modulate the effects of climatic change from one location to the next, e.g. warming could be expected to do little to increase the productivity of a nutrient-limited forest system. Nonetheless, across a broad range of forests, there are positive relationships (with considerable variability) between the temperature and either the total biomass or the net productivity of forests. Given an adequate supply of water and nutrients, one would expect global warming generally to enhance forest productivity. That most of the world's forests, however, are constrained to some degree by availability of nutrient and water needed for growth is a sufficient ground for caution with regard to this generalization. Through the use of remote sensing techniques, global environmental monitoring of productivity is now possible. These techniques also

have the potential to increase our understanding of the interactions between the biospheric productivity and the atmospheric systems.

Influence of contaminants

The influence of contaminants on photosynthesis of large trees growing under field conditions is very poorly understood. Experimental designs necessary for this research are very complicated and expensive. Soil moisture, relative humidity, temperature and light characteristics influence photosynthetic rates under natural conditions and all must be continuously and carefully monitored.

Legge et. al (1977) conducted field studies on photosynthesis in lodge pole pine × jack pine hybrids, white spruce, and aspen potentially influenced by sulphur dioxide and hydrogen sulphide from a natural gas processing plant in Canada. Small assimilation chambers were placed around portions of branches and used to monitor carbon dioxide flux. A 15-m high scaffold was used to gain access to mid-crown foliage of the pine hybrid (height 20 m). The spruce (height 3 m) and Aspen (height 2 m) were reached from the ground. Efforts to correlate trends in photosynthetic rates of these trees with episodic release of sulphur gases from the processing plant were frustrated by reduction in light quantity coincident with peak sulphur gas exposure. Moreover, since the measurements were made in September, the authors judged that foliar senescence may have been a factor in the metabolic responses observed. Nevertheless sulphur dioxide concentrations ranging from 5-10 pphm and persisting for several hours were recorded in the forest canopy studied. It was the authors' judgement that all the sampled trees exhibited less than expected photosynthetic rates.

Carlson (1979) evaluated the influence of SO_2, ozone, and combinations of both gases on 8- to 15-year-old saplings of black oak, sugar maple, and white ash collected from natural Connecticut forests. Treatments included fumigation at low (0.2-0.4), intermediate (0.5-0.6), and high (1.3-1.5 cal cm^{-2} mm^{-1}) light intensity and low (22-43%) and high (55-95%) relative humidity. Following one week of fumigation at low humidity and low light intensity, the rate of photosynthesis was 52, 46, and 80% of the control with 50 pphm sulphur dioxide; 52, 73, and 100% of the control for treatment with 50 pphm ozone; and 56, 59, and 62% of the control for treatment with 50 pphm sulphur dioxide plus 50 pphm ozone respectively for black oak, sugar maple, and white ash. After three weeks of treatment, SO_2 reduced photosynthesis to 26, 57, and 93% of control while ozone reduced CO_2 uptake to 57, 45, and 94% of control respectively in black oak, sugar maple, and white ash.

Simultaneous exposure to both SO_2 and ozone caused a greater than additive reduction in net photosynthesis during the first two days of treatment in case of sugar maple and white ash.

The increasing concentrations of greenhouse gases may result in a change in

the global climate that is probably warmer than at any time within the last 200000 years. During the past ages acute fluctuations in climate have been experienced, each of which was associated with terrestrial ecosystems that were markedly—in some cases dramatically—different in time and geographical space from those evident today. The warm period of the early Holocene period witnessed extraordinarily wetter conditions in the vast subtropical dry zones extending from West Africa to the Indus Valley-Rajasthan area; thriving savannah grasslands existed in large areas that are now unproductive desert (Hare 1979, Flohn 1980).

Past changes in climate were also accompanied by variations in the atmospheric concentration of carbon dioxide. However, it is not clear to what degree, if at all, variations in carbon dioxide concentration were involved directly in global-scale shifts of terrestrial ecosystems in the past, notwithstanding the fact that in experimental situations, higher CO_2 concentration has been repeatedly shown to stimulate plant growth and productivity. In this case, the distant past provides few clues for the future.

A fundamental difference between changes in global ecosystems of the past and those of the future is the dominating influence of human intervention in the natural environment. Just as human activity may be responsible for altering the state of the global climate, so, too, are humans capable of manipulating the global biota to a considerable degree. Deforestation by man has been a major contributor to past increases in the atmospheric CO_2 concentration and continues at an alarming rate in many areas of the tropics. In only a matter of centuries, one human activity, agriculture, has added another major terrestrial 'ecosystem', largely at the expense of grasslands and forests. This substitution still continues. Today, cultivated land (excluding pasture and grazing land) occupies about 10% of the world's land surface, an area approximately equivalent to one-third of that occupied by forests.

Miscellaneous changes

There are no firm grounds for believing that the net effects of increased CO_2 and climatic changes will be adverse rather than beneficial. At the extreme, some assessments like the 'Global 2000 Report to the President' (U.S. Council on Environment Quality and Department of State, 1980) see future changes in climate coinciding with deteriorating conditions in agriculture, forests, and other resources, and thus paint a very gloomy picture indeed. In contrast, Simon and Kahn (1984) examine the same issues and, in a strongly optimistic tone, reach just the opposite conclusions. In fact, at a global scale, the uncertainties that are involved in both sets of analyses are large enough to accommodate both views. The possible adverse consequences of climate-related ecosystem changes are gradual and to an extent speculative. Forestry as an empirical science used in the management context is highly dependent on data or local knowledge of forest response to specific management treatments. Under a sufficiently large change in climate, this local knowledge base

would have to be used outside its applicable range and the consequences of management actions would be less certain. The global pattern of many of the ecological processes in natural systems could be altered if the climate changed. Insect pests, pathogenic organisms, and wildfire frequencies could all change. While the prediction of such changes is highly uncertain, their potential impacts are quite large.

In a nutshell, the climatic changes will have the following implications for forestry:

- Mortality may increase in sal forests, dry deciduous forests, and mangrove forests.
- Droughts and fire will eliminate many useful species and there will be invasion by unwanted species.
- Pest outbreaks may destroy plantations of fast-growing species.
- Inhospitable sites will increase and the productivity of forests will decrease in dry deciduous, arid and, semi-arid forest areas.
- In the grassland, productivity of fodder grasses will decrease.
- Sustainable management of forest will require increased investment in raising plantations, conserving them, and protecting them from fire and pests.
- Hardy broad-leaved species of moist areas may improve their productivity.
- There will be problems in utilizing the lower quality wood grown under stress and at prohibitive costs.
- Production of non-wood products from forest will decrease owing to insufficient accumulated winter chilling. This will adversely affect the economy of tribals.

Attempts should be made to check deforestation and a major research effort should be rapidly carried out in the fields of tree physiology, infraspecific variability of adaptive characteristics, biological control of insects and pests, and fire management.

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Agriculture: culprit and victim

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Global warming is commonly perceived to be the product of industrialization but agriculture is also a culprit. Indeed, since farming first began it has been a producer of greenhouse gases, in particular carbon dioxide, methane, and nitrous oxide. What has changed in recent years is the scale of production as agriculture has expanded and intensified. For example, the area of irrigated paddy land in Asia has grown by 40% since 1970, resulting in increased emissions of methane. Similarly, the worldwide growth in use of inorganic nitrogen fertilizers—up from 20 to nearly 80 million tonnes annually since the mid-1960s—has contributed to a rapid rise in nitrous oxide production. Intensification of livestock husbandry has also brought about more emissions of methane. And the clearance of forests and grasslands has increased production of carbon and nitrogen oxides (Figure 1).

Greenhouse gases from agriculture

Methane (CH_4)

Agriculture is an important producer of methane, contributing about 45% of total emissions (natural plus human-made) in 1990. Methane is produced by specialized bacteria in environments that are free of oxygen, and during the burning of biomass. Anaerobic conditions occur naturally in wetland ecosystems—swamps and marshes —and in their agricultural equivalent, the rice paddy. They also exist, on a much smaller scale, within the guts of cattle and other ruminants, as well as in wood-eating insects, such as termites.

In normal, well-drained soils, aerobic bacteria break down organic matter to produce carbon dioxide and various oxides of nitrogen. By contrast, the decomposition in flooded soil is by anaerobic bacteria and the end-products, in addition to carbon dioxide, include methane, hydrogen sulphide, and various other gases (Sanchez 1976). Organic rich wetlands are particularly important sources of

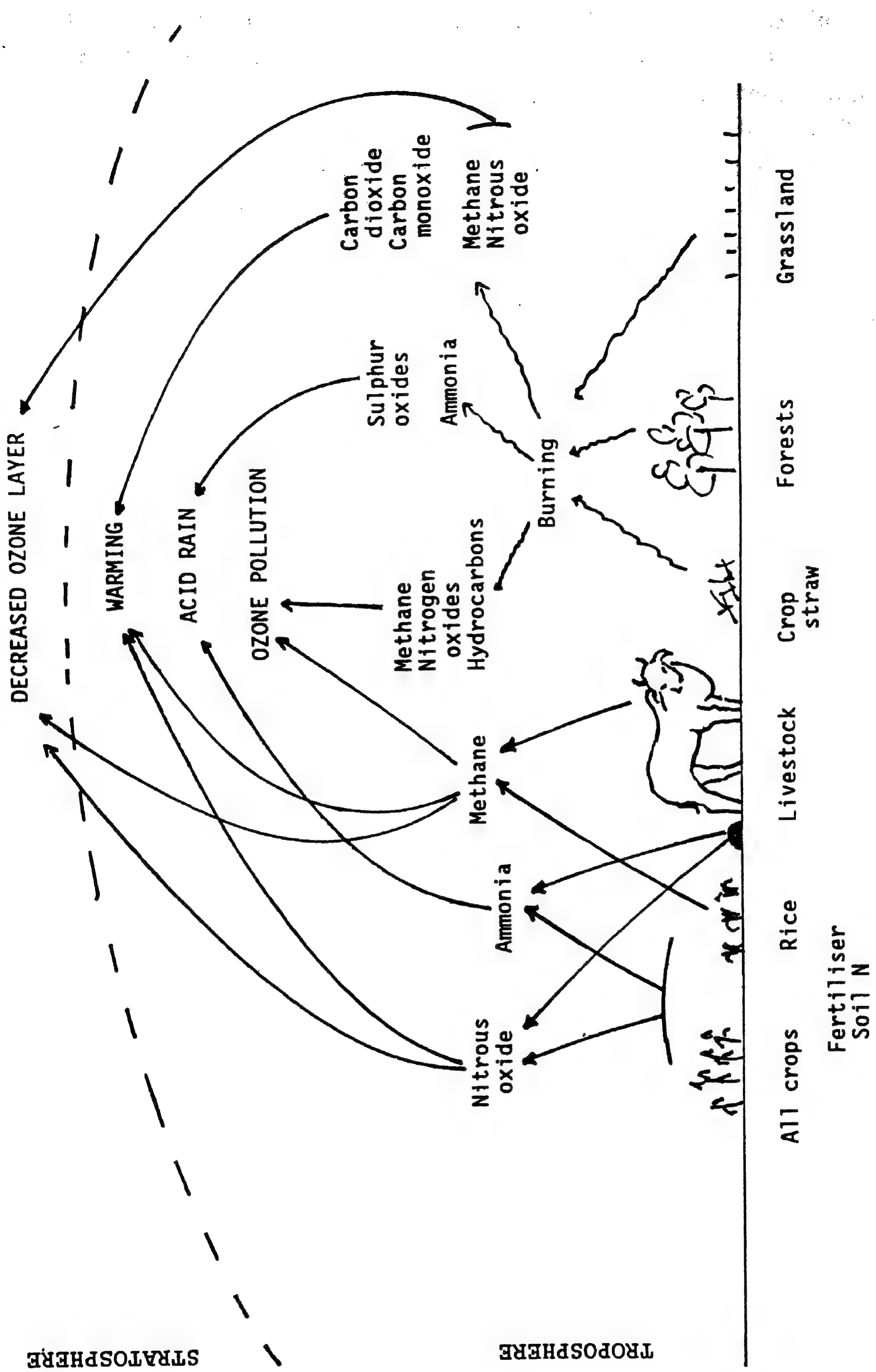

Figure 1. The principal atmospheric emissions from agriculture and their immediate impact. (*After* Conway and Pretty 1991)

methane: emissions from the Amazonian floodplain, alone, are estimated to be 8-21 million tonnes annually (Devol et al. 1988, Bartlett et al. 1988). Natural wetlands probably contribute 20% to global methane emissions.

Rice paddies generate about the same amount and, together, natural wetlands and paddy produce about 40% of methane worldwide. Compared with wetlands, paddy fields are capable of producing double the maximum daily emission rates per unit area, though these high levels mostly occur in the first six weeks after the fields are flooded and are not sustained throughout the growing season (Holzapfel-Pschorn and Seiler 1986). However, there are a great many uncertainties in the estimates. Few experiments have been conducted in tropical conditions; and those that have measured methane emissions have produced widely divergent results. Methane efflux may vary from 0.07 to 80 mg per metre^2 per hour depending on soil type, soil temperature, pH, rice variety, and fertilizer type (Parashar et al. 1991). Emissions are reduced when nitrogen is applied as ammonium phosphate, but greatly increased when green manures are used.

A preliminary estimate of the total emissions from Indian rice paddy is 3-9 million tonnes per year (Parashar et al. 1991).

Methane production by livestock also results from the activity of anaerobic bacteria, breaking down organic matter in the animal's gut. The amounts produced are still uncertain. One estimate indicates that individual cattle, buffaloes, and camels produce 35-55 kg/year; goats, sheep, and horses, 5-15 kg and pigs, 1 kg (Crutzen

Table 1. Estimates of annual emissions of methane by source (1990). The total source is not necessarily calculated from the sum of the indicated individual sources.

	Emission of methane (million tonnes/year)	
	(1)	(2)
Rice paddies	25-170	60-140
Domestic ruminants	65-100	65-100
Natural wetlands	100-200	40-160
Termites	10-100	10-100
Fossil-fuel production	40-100	50-95
Biomass burning	20-80	50-100
Oceans and freshwaters	6-45	15-35
Landfills	20-70	30-70
Methane hydrate destabilization	0-100	-
Total (estimated range)	350-600	400-650

Source: (1) Watson et al. 1990, (2) Bouwman 1990

et al. 1988). Because of their large numbers—about 1.4 billion worldwide in 1988—cattle and buffaloes produce about 80% of all the methane emissions from animals (FAO 1989, Bouwman 1990). Overall, ruminant animals contribute about 15% of total methane emissions.

The burning of agricultural wastes, fuelwood, vegetation during swidden (slash and burn) cultivation, and grasslands on savannahs is a further important source of methane, probably about 8% of all emissions (Watson et al. 1990, Bouwman 1990).

Over the past 150 years methane concentration has increased from about 700 ppbv (parts per billion by volume) to a level of 1720 ppbv in 1990, presumably as a consequence of increased agricultural activity as well as the burning and mining of fossil fuels (Watson et al. 1990, Blake, and Rowland 1988, Bolle et al. 1986). The levels are also now significantly higher in the northern than in the southern hemisphere, reflecting the differences in the scales of both agricultural and industrial activity.

Nitrous oxide (N_2O)

Agriculture has a relatively smaller impact on the global cycle of nitrous oxide, but it is nevertheless important. Both the growth in nitrogen fertilizer use and the clearance of land have contributed to rising concentrations of N_2O in the atmosphere (Table 2).

Nitrous oxide is produced naturally by the action of bacteria in soils and water and by the burning of biomass and fossil fuels containing nitrogen. The most important natural source, accounting for some 20-30% of total global emissions, is

Table 2. Estimate of annual emission of nitrous oxide by source (1970).

	Emission of nitrous oxide (million tonnes/year)
Fertilizers	0.01-2.2
Biomass burning	0.02-0.2
Soils	
tropical forests	2.2-3.7
temperate forests	0.7-1.5
Oceans	1.4-2.6
Fossil fuel use	0.1-0.3
Unaccounted sources	4
Total emission (calculated from atmospheric build-up and main sinks)	14

Source: Watson, et al., 1990

bacterial action on natural nitrogen compounds in tropical soils (Watson et al. 1990, Keller et al. 1990, Matson and Vitousek 1987). Emissions are particularly high from soils covered by undisturbed tropical rainforest, producing in the Amazon region greater tropospheric N_2O levels than the global average (McElroy and Wofsy 1986). Atmospheric emissions are usually much lower from temperate forests, although the amounts reaching surface waters can be high (Keller et al: 1988, Keller 1988). Cutting forests can cause an immediate increase in atmospheric emissions, but the amount of N_2O dissolved in soil water can multiply a hundred times and on reaching surface streams will also escape to the atmosphere (Bowden and Bormann 1986). After a time, however, the emissions decline.

In addition to breaking down natural soil nitrogen, bacteria will also liberate N_2O from nitrogen fertilizers. Soils that have been fertilized emit between two and ten times as much as unfertilized soils and pastures, though there is considerable variation in experimental results. One factor is the type of fertilizer. In temperate countries, ammonium and urea compounds tend to produce the highest emissions with up to 2% of added nitrogen lost as N_2O. As yet there is insufficient experimental evidence of this behaviour under tropical conditions but if urea is more prone to N_2O loss, as the results suggest, this is significant since urea tends to be the preferred fertilizer in the developing countries. Over 70% of total fertilizer consumption in Asia is of urea, and an increasing proportion of new manufacturing capacity in Asia is being devoted to urea production (Prasad and De Datta 1979).

In a similar fashion, livestock wastes are a source of N_2O: some studies have shown high and continuing losses when animal wastes and slurry are applied to land. In one case some 50 kg of nitrous oxide as nitrogen (N_2O-N) per hectare per year was emitted from a manured soil in Denmark (Ryden 1985, Christenssen 1985).

At present, atmospheric N_2O is increasing at a rate of 0.2-0.3% per year, with nitrogen fertilizers contributing an estimated 5-20% of total emissions (Watson et al. 1990, Rasmussen and Khalil 1986, Bolle et al. 1986, Pearman et al. 1986). Although reductions in nitrogen fertilizer use could limit this trend, the very long atmospheric residence time of the gas—about 170 years—implies that an atmospheric steady state will only be approached some 150 to 200 years after the emission rates have become constant (Ko and Sze 1982, Bolle et al. 1986). Furthermore, emissions will not be reduced by the destruction of tropical forests, since pastures recently converted from forest can be very significant sources of nitrous oxide (Luizao et al. 1989). Present trends are thus likely to continue for some time to come, whatever the changes in agricultural practice.

The products of burning

A further major source of global air pollution is the burning of vegetation, in particular during the clearing of forest, scrub and grassland to make way for

agriculture. When vegetation is burned, carbon and sulphur are released, together with the accumulated nutrients—nitrogen, phosphorus and potassium. If the burning is carried out in situ, most of the potassium and phosphorus are returned to the soil, but the remaining constituents are emitted to the atmosphere in the form of carbon monoxide and carbon dioxide, nitrogen oxides, nitrous oxide and ammonia, methane and other hydrocarbons, as well as various sulphur products.

This is not a new phenomenon; it even predates agriculture. Hunter-gatherers have long known how to create fire and to use it to improve grazing grounds. What has changed is the extent and amount of burning that goes on each year, as more and more land is cleared.

The largest clearance of land is still for shifting—or swidden—cultivation, the predominant form of agriculture in many upland regions of the tropics and subtropics. Primary or secondary forest or savannah land is cleared and as much of the dead plant material as possible is burnt on site. The soil, enriched by the potassium and phosphorous from the burnt vegetation, is then sown with a variety of crops. Yields are usually high in the first year but then decline as nutrients are depleted and weeds increasingly invade. Eventually the clearings are abandoned, to become covered by secondary vegetation which returns slowly to savannah or forest. The land may be cleared and burned again after a fallow time of five to ten years, depending upon such factors as soil fertility, population density, and climate. Estimates are difficult to arrive at, but it is believed that 200-300 million people are supported by swidden, and they annually clear 20-100 million hectares of tropical forests and savannah (Seiler and Crutzen 1980, Greenland and Okigbo 1983). The efficiency of burning is usually low and, despite the fact that burns are often repeated, only 25-75% of the cleared biomass is finally burned. Nevertheless, on these estimates, between 0.9 and 2.5 billion tonnes of dry matter is burned as part of the swidden cycle each year (Table 3).

It is also common practice in savannah regions to burn dead vegetation in the dry season so as to enhance the growth of grasses and hence improve grazing. Much of the African savannah is burned at least once every three years, while in South America 20% of the savannah—the Cerrado—totalling some 40000 km^2, is subjected to fire each dry season (Delany et al. 1985). Observations from the air indicate that plumes cover about 5% of the Cerrado at any one time and smoke, dispersed within a 3 km deep inversion layer, can cover the whole region.

In addition to swidden clearance—which is itself increasing because of population pressure and competing demands for marginal land—there has been rapidly growing clearance of forests and savannah to make way for permanent agriculture and livestock raising, as well as for settlements and highways. Some 8-15 million hectares are cleared annually for these purposes, with the increasing cattle population alone accounting for about half of global deforestation (Seiler and Crutzen

Table 3. Global estimates for cleared area and burnt biomass due to various activities.

	Cleared or burned area (million ha/year)	Burned biomass (billion tonnes/year)
Swidden (total)	20.5-61.5	0.9-2.5
Asia	10-30	
Africa	8-24	
Latin America	2.5-7.5	
Other deforestation (total)	8.8-15.1	0.55-0.9
Permanent agriculture and livestock	8.3-14.3	
Colonization	0.4-0.7	
Highways	0.1	
Wild fires in savannah and temperate and tropical forests		0.7-2.2
Burning of industrial and fuel wood		1-1.2
Burning of agricultural wastes		1.7-2.1

Source: Seiler and Crutzen 1980.

1980). In the Amazon region probably as much as 90% of the burning is to open the land for livestock raising.

The Greenhouse Effect

Of the greenhouse gases, carbon dioxide is the most important, responsible for more than half of global warming. However, over the past decade methane and nitrous oxide have contributed more than a fifth. The increases in all these gases have already caused a temperature rise of 0.3-0.6 °C this century. Based on the 'business-as-usual' predictions the global temperature will rise by 0.3 °C per decade (range 0.2-0.5), causing a mean sea level rise of about 6 cm per decade (range 2-10 cm) (IPCC 1990a). But there are many uncertainties. Estimates are complicated by two factors—the residence times of gases in the atmosphere and the presence of various feedback mechanisms. Reducing emissions of these gases will not reduce concentrations immediately, as some persist for a long time in the atmosphere: for CO_2 and N_2O residence times are about 100 and 170 years respectively, although for methane only 8-12 years.

The impact on agriculture

The consequences of global temperature increase on agriculture are likely to be serious, although they will vary from place to place and in ways that are still very uncertain (Parry 1990, IPCC 1990). Weather patterns will shift and sea levels will

rise, initially from thermal expansion of the oceans and, perhaps eventually, as a result of melting of the polar ice caps. Warming will be greatest at high latitudes. Potentially this may increase agricultural production, although it is thought that the gains are unlikely to outweigh the substantial losses in potential at mid- and low latitudes (Parry 1989, Parry 1990).

At these latitudes the major factor will be worsening water availability. Monsoon rains may penetrate further poleward, resulting in higher total rainfall in such drought-prone regions as north-west India. But it is possible that the increase in rainfall may come in the form of more intensive rainstorms occurring over a shorter rainy period. This may exacerbate problems of flooding and soil erosion, and more importantly may result in a diminution of the pre-monsoon rains that are so essential for crop germination (Parry 1990).

Warming at low latitudes, although less in magnitude, will also have a negative effect on agriculture. General circulation models indicate a 2-4 °C rise in the winter months (December through February) in India and a 1-2 °C rise in the monsoon (June through August) as a consequence of a doubling in CO_2 (Subramaniam 1991). In northern India where wheat is growing close to its upper temperature tolerance, yields may decline due to heat stress. The fall could be of the order of 10% for a 1.0 °C warming (Abrol et al. 1991). Higher temperatures will also increase evapotranspiration, so reducing yields, particularly of dry season crops. But rice yields may increase if higher temperatures are accompanied by higher rainfall (Van Diepen et al. 1987).

Accompanying these changes is a growing probability of short-term extreme climatic events. Floods, droughts, hurricanes, and severe freezes may become more common, with especially serious consequences for more marginal farmers. Crop and forage yields are more sensitive to changes in seasonal rainfall in the semi-arid tropics than in the humid regions; year-to-year variability tends to be greater and yields can be considerably lower in the driest years. During the 1980s, persistent droughts in the Sahel, north central India, north-east Brazil, south and eastern Africa, and Australia led to hardship, famine, out-migration and forest fires. These may well become more frequent and widespread.

Apart from the indirect climatic effects, rising levels of CO_2 may have a direct effect on crop physiology. Under experimental conditions a doubling of CO_2 can increase yields of C_3 cereals, such as wheat, rice, barley, and sunflower, by some 30%. (Plants differ in their photosynthetic processes. Plants with the C_3, as distinct from the C_4, photosynthetic pathway use up some of the solar energy they absorb in photorespiration. Increased CO_2 reduces photorespiration and hence results in a greater production of carbohydrate) (Parry 1990, Hillel and Rosenzweig 1989, Warrick and Gifford 1986). By contrast, C_4 plants such as maize, sorghum, sugarcane, and millets, are less responsive and Parry suggests that in the semi-arid tropics this

may accelerate the current trend away from these crops towards wheat, rice, and barley (Parry 1990). CO_2 also affects the opening of the stomata (the apertures on the leaf surfaces of plants through which water vapour is lost during transpiration). Under experimental conditions a doubling of CO_2 reduces stomatal apertures sufficiently to produce a 23-46% fall in transpiration (Cure and Acock 1986). This may help offset the predicted higher evapotranspiration losses in the semi-arid tropics, but far too little is known to make reliable predictions.

Agriculture without pollution

An agricultural system that does not cause pollution is an impossible goal. All productive processes, whether they be of industry or agriculture, involve transformation of inputs of one kind or another to useful outputs, and the conversion can never be a 100% efficient. There is always a waste that goes into the environment.

One way of reducing gaseous waste is simply to cut back on production—to halt agricultural expansion, to reduce the area of land under paddy cultivation, and to cut back on fertilizer use. But this will undoubtedly mean less food production. If production is to keep pace with growing populations, agriculture will need to become even more intensive. The challenge, therefore, is to find new technologies that will reduce gaseous emission levels while, at the same time, permitting greater production (Ehrlich 1990).

For example, there is theoretically scope for reducing methane emissions. Microbiologists and dairy nutritionists have long been interested in reducing methanogenesis in dairy cattle since it represents a net loss of energy from the animal and so reduces the efficiency of milk production. But the complexity of the food chain and the critical role of the bacteria in digestion have made the task difficult. Methanogenic bacteria from the rumen have been shown to be inhibited by antibiotics such as monensin, but this only lasts a short while, the bacteria evolving resistance to the antibiotic (Chen and Wolin 1979). In the long run finding an appropriate methanogenesis-inhibiting substance to add to feed could both improve efficiency and reduce pollutant emissions.

There are also possible benefits in changing the nature of cattle feed. High quality feed containing a high proportion of starch to cellulose lowers methane emissions. Grain-fed cattle emit less methane per kilo of meat produced than do range cattle with a high cellulose diet (Ehrlich 1990, Blaxter and Clapperton 1965). But, of course, shifting to more intensive livestock rearing will only increase the ammonia pollution arising from livestock waste.

Antibiotic and other inhibitors may also reduce methane production from paddy fields. An alternative approach is to breed new varieties of rice that leave less stubble in the fields. It has also been suggested that the cultivation of fish in paddy fields may reduce methane emissions (Ehrlich 1990).

So far, few researchers have investigated means of reducing the losses from cropped fields of nitrogen as nitrous oxide. Nitrification inhibitors added to fertilizers have been shown to inhibit bacterial action and reduce gaseous losses, but their use is still largely experimental. Further investigation may also identify formulations of fertilizer and methods of application that reduce nitrous oxide emissions.

Research may eventually come up with other options: strains of bacteria that absorb gases as they leave plants or capture gases from the soil as they pass by crops; or rice varieties that inhibit methane production in the root zone. But such developments lie some way in the future.

Finally, there is a need to reduce the amounts of biomass burnt, either during swidden cultivation or in clearing for new agricultural lands. The alternative to swidden cultivation is to invest in the development of more permanent and productive agroforestry systems. There is good evidence that these can provide livelihoods as productive as those of swiddening without the need for burning. In savannah agriculture the alternative is not so clear. For the long term, the answer may lie in upgrading grasses using species that do not require burning to stimulate new growth.

The clearing of new lands is particularly difficult to control. In India and most other developing countries, the potentially cultivable land is already exploited. The major land clearances, today, occur in the Amazon basin, in parts of central Africa, and in Indonesia and Malaysia. Although these are partly a function of population pressure, they are more directly a result of unbridled investment by larger entrepreneurs seeking the timber wealth and the opportunities for large-scale agriculture.

Conclusion

Agriculture is a major source of atmospheric pollution. Paddy fields, the guts of livestock and the burning of vegetation, together, produce some 45% of global methane emissions, which are currently 400-640 million tonnes annually and increasing at a rate of about 1% per year. In the 1980s methane produced by agriculture contributed about 7% total global warming (Table 4).

Agriculture is a less important, but nevertheless significant, source of nitrous oxide emissions, arising from nitrogen fertilizers, livestock waste, and the burning of vegetation. About 14 million tonnes a year are produced, 10-25% from agriculture. Levels are rising at about 0.2-0.3% per year, driven mostly by increasing nitrogen fertilizer use. In the 1980s nitrous oxide produced by agriculture contributed 0.6-1.5% of total global warming.

The single main cause of global warming, however, is carbon dioxide, estimated to contribute about half of the projected warming over the next 50 years. Burning

Table 4. Contribution (%) of agriculture to total production of methane and nitrous oxide.

	CH_4	N_2O
Agricultural contributions to total emissions		
Paddy rice	21	-
Livestock and wastes	15	unknown
Biomass burning	8	5-20
Fertilizers	-	5-20
Total contribution	44	10-25
Agricultural contribution to global warming	7	0.6-1.5

of biomass produces carbon dioxide equivalent to 50-100% of that from burning of fossil fuels and, of the former, agriculture is responsible for 60-65%. The principal sources are the practice of shifting, or swidden, cultivation, the annual burning of savannah lands and the clearing of forest and savannah for livestock and arable farming.

The consequences of global warming on agriculture are difficult to predict. Warming will be greatest in the high latitudes, but nevertheless significant in the mid- and low latitudes. In India wheat may suffer from heat stress, but rice yields could increase. The dominant factor in India is likely to be higher rainfall, but in the form of more intensive downpours over a briefer monsoon period. There could be a diminution of the pre-monsoon showers. Higher CO_2 levels may directly favour cereals such as wheat and rice over maize, sorghum, and millets.

Although, in theory, there is much that could be done to reduce agricultural emissions, practical measures are largely dependent on more research. A reduction in biomass burning, through the development of agroforestry, is possible and will significantly reduce CO_2, but the means of reducing methane and nitrous oxide emissions are poorly understood.

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Global warming: water resources

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Mr Chairman, Ladies, and Gentlemen,

A great deal of uncertainty surrounds this issue and we have just been told that all that our climatologists give us is what the average results might be. The average conceals the extremes which are what concern us because it is what happens at the margin that often determines the outcome. We say there will be global warming but how will it be distributed regionally, world-wide, and within regions?

I shall take a look at the Indian subcontinent which is a homogeneous Himalayan monsoonal region. One element of insurance, even with talk of a poleward movement of temperature, precipitation, and so on, is the Himalayan shield, which seems likely to ensure that while the distribution of rainfall may alter, this region will still capture a good part of the moisture in the monsoonal current. But the spatial variations and perhaps the seasonal variations are going to be very important.

If one looks at the demand side, there is in any case going to be an increasing demand for water. The first factor is population growth. We are already 850 million in India and over the next 50 years this figure might to up to about 1500 million. That would requre larger quantities of food grains to be grown—something of the order of perhaps 400 million tonnes as against 180 million tonnes at present.

Drinking water requirements are not quantitatively large but very important is our ability to supply it where it is needed and during seasons of shortage. India already faces very acute problems of drinking water. We have tens of thousands of what we call 'problem villages' that still lack any kind of protected or assured water supply. This problem will aggravate if there are climatic shifts. Then there are industrial and municipal uses, which account for only a small part of our water requirements at present but which, with an improved quality of life and industrialization, are going to demand very much more water in the future. With population increase and agricultural and industrial demand, stream flows would need

to be maintained in order to dilute the sewage and other pollutants that enter the rivers so as to ensure minimum ecological standards, control salinity, and protect our fisheries.

On the supply side, there are uncertainties about the quantum and the distribution of rainfall. To that we must add snow and ice. We get the south-west monsoon in the summer months and a small north-east or winter monsoon in the southern part of India and Sri Lanka. If these currents move up, we are going to get larger quantities of rainfall striking the Himalayan shield and falling in the Ganga, Brahmaputra and Indus plains and along the mountains. But perhaps we shall have less rain in the southern and western parts of the subcontinent. And that could be calamitous for those areas.

As far as snow is concerned, it comes with the westerlies in the winter. If these circulation patterns are affected, then one has to contend with the possibility of reduced snowfall, though higher summer temperatures would temporarily enhance snow and ice melt during the dry months. However, retreating glaciers could lead to long-term consequences such as reduced ice melt, which is very important for maintaining Himalayan river flows in the north-western region.

Such a change in moisture distribution could also lead to increased flooding in areas of greater precipitation, which are already more prone to floods. It would particularly affect the Ganga-Brahmaputra plains and Bangladesh where all these great rivers funnel into the sea. Conversely, there could be increased drought in the western and southern parts of India which already experience it. The seasonal cycle of flood and drought may be accentuated. That is something which could affect agriculture and society generally.

The warming process and precipitation changes will also affect ground-water recharge though much will depend upon how those changes occur, and their extent and spatial distribution. Because of the likelihood of enhanced floods, drainage is going to become very much more important than it is today. As it is, this is a neglected aspect in Indian water planning and is going to require a great deal more attention particularly in the lower Ganga-Brahmaputra basin and Bangladesh, which regularly experience very heavy floods and are at the tail end of a whole drainage basin that receives very high precipitation. Water-logging and water-locking because of poor drainage are also going to need greater attention. The flood prone areas could increase.

If there is a rise in sea level, then that is going to affect coastal aquifers apart from causing coastal flooding as a result of storm surges and cyclones that sweep up the Bay of Bengal and visit Andhra Pradesh, Orissa, West Bengal, and Bangladesh coasts with devastating regularity in certain seasons. This will be a major problem. One-third of Bangladesh is already below the high tide level. Any rise in sea levels is going to aggravate flooding. There will be a considerable loss of agricultural land

and ingress of salinity further inland with adverse effects on aquifers, water supply systems, and agriculture.

Even sewerage systems are going to be affected. In Bombay, for instance, when there is a high tide, the sewage outlets are submerged and there is a blockage resulting in local flooding. This could happen on a more extensive scale in coastal areas. Engineering remedies would be called for to re-model old systems; sewage systems that are yet to be constructed would have to be designed differently.

Saline instrusion is something to safeguard against. Increased consumption of ground-water could also make for further ingresses of salinity. Clearly, if the salinity line moves further inland, it is going to pose many problems.

Estuarine fisheries and mangroves would certainly be affected by sea level rise and so will ports, inland water transport, and coastal drinking water supplies. It will be necessary to release more fresh water downriver in the lean season to meet the ingress of saline water. All this is going to necessitate careful study and adoption of new parameters of water management and in the use of the total available water seasonally and over the year.

The aggravation of alternating flood and drought will call for much better weather forecasting, disaster preparedness and, crop and cattle insurance. The construction of lifeline structures such as roads, water supply systems, and electricity transmission lines on high ground will be necessary so that they are not affected by floods as often happens in the eastern part of the subcontinent.

On the supply side, there is certainly going to be much more need for water conservation and recycling, particularly for industrial and municipal uses, the use of sea water where feasible, and increasing the efficiency of water-use. Water-use is estimated as a certain average water allowance for maturing various crops in the country as a whole. The National Commission on Agriculture (1976) lowered the figure that the Irrigation Commission had allowed about five or six years earlier. More recent studies have sought to lower that figure further by assuming a greater efficiency of water-use. But if there is global warming then all these numbers are going to change. How global climate change will affect agriculture in terms of seasons, growth periods, soil moisture, and so on has been suggested by Dr Warrick.

Water pricing will become more important than it is now. Low water charges result in wasteful and inefficient use. There is greater need for training in and implementation of better water management practices as also for a review of cropping patterns. Participatory systems of irrigation, with water-user management systems, would bring about a greater degree of efficiency and less waste.

In terms of irrigation practice, drip and sprinkler systems are coming into vogue. These are expensive but good for high-value crops and will probably be used increasingly. Irrigation systems need to have better control structures while canal

designs would need to undergo change. Water management and watershed management are becoming increasingly important.

One of the things we need to do is to improve the training and education of engineers and agronomists so that they become inter-disciplinary specialists who understand the whole land-water cycle, including forests.

To meet the challenge ahead, storage will become increasingly important. Water must be harnessed wherever it falls—in the fields, in small tanks, village ponds, water harvesting systems, and medium and large storages, depending upon opportunities and requirements. We have a fairly large storage system in India but we harness or store only about half the quantity of water that could perhaps be captured, which again is a fraction of the potential because of a lack of storage sites and other technological problems. We experienced a very severe drought in 1988 that affected large parts of the subcontinent. At the same time, areas with irrigation, particularly in north-west India, flourished agriculturally without any impact of that drought because of the availability of stored water, some of it fed by snow melt. Storage also allows you to tide over a bad year because you can carry over storage from one season to the next if you have had a good year. That again is something that has happened.

There is a proposal to transfer water from surplus areas, that is from rivers with surplus water in relation to population, cropped area, and other uses, to deficit areas. Many years ago one of our ministers for irrigation, Dr K L Rao, proposed linking the Ganga to the Cauvery right down south and currently the scene of a great deal of trouble and turmoil over water sharing. That concept was modified and a National Water Grid has been proposed by the Central Water Commission. This is a long-term scheme for diverting the surplus waters of the Ganga, Godavari, and Mahanadi rivers southwards and westwards through a series of links and of certain west-flowing rivers eastwards. But the one truly large surplus source in the subcontinent is the Brahmaputra system. One-third of India's water resources are located in the north-east. This is far in excess of regional requirements whether in the mountainous upper reaches of Arunachal, the narrow Assam valley, or in Bangladesh. The Brahmaputra carries a much larger volume of water than the Ganga. Very little of this flow is used at present. So inter-basin transfers, selectively and sensibly executed, need to be looked at if we are to re-distribute the monsoon and ensure water availability over space and time.

The Aswan Dam, despite all the criticism it attracted earlier on, has in the past few years helped Egypt overcome devastating droughts because of the carry-over factor, that is, its ability to store large quantities of water. There are costs in dam construction, and there are good dams and bad dams. The argument about big and small dams is irrelevant as also the choice between surface and ground water which are part of the same hydrological cycle. There will certainly be some loss of forests

and displacement by submergence behind dams. This is a problem. But given the other gains, if one weighs the two, one can come to sensible decisions about where and how to construct these dams. And compensatory afforestation, a concept erroneously scoffed at, is by no means irrelevant. By making water available in the plains one can create forests and shelter belts. Otherwise too, in all irrigated areas, there is much more greenery in the form of crops, trees, plantations and so on.

The greening of the Himalaya, a critical global watershed, is something that we need to promote. The Himalaya moderates the weather and regulates the water supply of this whole subcontinent which, although a relatively small region compared to the rest of the world, accounts for a very large part of the world's population.

Many of these proposals imply a great deal more regional co-operation because of the interdependence created by these international river systems. Nepal, Bhutan, and the Himalayan regions of India and Pakistan benefit from snow melt and monsoonal rainfall. But the southern and western semi-arid and arid regions also require water. As against this, Bangladesh and the lower part of the Ganga-Brahmaputra basin experience devastating floods every year. The floods play havoc, increase agricultural risks, inhibit investments, and wipe out infrastructure. They produce a whole cycle that keeps these regions and people backward. So we need regional co-operation to deal both with floods and drought. In dealing with one we are dealing with the other because they are two facets of the same coin.

Hydro-electric power is a cheap and renewable energy source. Stored water, whether for irrigation or flood moderation, also has the capability of generating large quantities of cheap electricity. The potential in the Himalayan region excluding Pakistan but taking in Bhutan, Nepal, and India is something of the order of 150 000 MW. If you harness the Brahmaputra U-bend from China into India, you add another 50 000 MW. Perhaps not all of it can be tapped, certainly not at current prices, but there is a large storehouse of energy that could be and needs to be used for ground-water lift, industry, and everything else.

There needs to be some strengthening of water laws, both national and international. These are still at the level of guidelines. The International Law Commission of the United Nations is working on this. It has evolved a set of principles which has undergone a great deal of scrutiny and discussion. A consensus is emerging.

Parts of India are short of water as also many parts of Africa, Central Asia, West Asia, and parts of the United States. These are going to be areas of increasing stress with climate change and all the uncertainties that are there. Water as much as energy is going to be on the agenda of nations as well as globally in the years ahead.

India has one other water reserve. There is a hypothesis which needs to be explored—why we have not done so is not very clear—of very deep aquifers, formed during glacial periods, underlying the northern Gangetic plain in India and also the

Bengal Basin in West Bengal and Bangladesh, with the possibility of similar pools in Nepal and Perhaps Burma. This hypothesis has been around for many years and exploratory programmes have been suggested by the World Bank but, for various reasons, it has not been pursued. This is a pity. If there is a fresh water aquifer under artesian pressure that is being recharged from the Himalaya, it would be a matter of very considerable importance not merely as insurance but in determining how we should develop our water resources and plan for the future.

The uncertainties of climate change are there. But it is wise to be prepared. This is the time when we need to gather data, undertake studies and training, and build up the systems that could serve us well in the future. To some extent we already have that experience because of alternating flood and drought, good years and bad years, warm years and not so warm years. Perhaps we need to transfer these year-by-year exercises, which we have done for drought-proofing, flood-proofing and so on, to something that will encompass the future in terms of long-range management of water resources.

PANEL DISCUSSION

Session 2a
Impacts (agriculture, forests, and water resources)

Dr H S Rao (National Institute of Science, Technology and Development Studies)
One way of looking at the methane issue is this: if all the paddy cultivation in the world is stopped, would the rate of increase in methane go up, come down, or remain the same. Methane apparently comes from two sources, organic humus in the soil, which is used during paddy cultivation, and biomass, which would be there in any case. Secondly, methane, ammonia and oxygen combination is not the same as methane taken in isolation. Methane reacts with ammonia and oxygen to give HCN which is either hydrolysed to give formic acid or stays as it is, especially in the presence of oxides of nitrogen or an electric arc discharge. The kind of methane that is generated during the decomposition of humus or other organic matter normally has ammonia associated with it along with oxygen. Therefore, we should look at this as a total system—methane, ammonia, and oxygen and not just at methane in isolation.

Professor Conway
Thank you. The second point is very well taken. On the question of what happens if you replace rice paddy, the critical factor seems to be whether you are replacing it with something that also has anaerobic conditions associated with it. If you replace rice paddy with some other kind of wetland production, the methane emissions will remain the same.

Member of the Audience
Methane-ammonia-oxygen system is an altogether different entity from methane gas taken in isolation because methane reacts with ammonia in the presence of oxygen to give HCN in a chemical reaction. This is a well known reaction called amoxidation.

Speaker
I think what you are saying is important but the major sink for methane in the environment is OH, not ammonia. This reaction of ammonia, oxygen and methane does occur but on a much smaller scale as compared to the oxidation of methane.

Member of the Audience
Have any measurements been done at all relative to this system? Are any data available or is your reply purely speculative?

Speaker
With OH definite data are available. The recent measurements at NASA by Ravi Shankar have proved that the reaction rates of methane and OH are 25% slower than what was projected earlier, and the budgets are being revised accordingly. However, I cannot comment on the rate of the ammonia-methane-oxygen reaction.

Dr K S Gupta (Rajasthan University)
Under atmospheric conditions, the reaction between ammonia, methane and oxygen is thermodynamically impossible; under drastic conditions, it is not likely to be relevant.

Dr A K Bhattacharya, Jawaharlal Nehru University
Sustainable agriculture requires both organic and inorganic manures and fertilisers. If 50% or more of methane emissions are from agriculture, do you mean to suggest that we shall have to reduce the use of fertilizers? How do we sustain agricultural productivity then, keeping in view the growing population of developing countries?

Professor Conway
You are right in saying that both organic and inorganic forms of fertilizers will have to be used in future. And you are going to have to increase nitrogen application to crops from one source or another if you are to increase grain production. Unfortunately, we do not yet know the rate of contributions of organic and inorganic fertiliser, particularly of the different forms of organic and inorganic sources, and their impact on both methane, ammonia and nitrous oxide production. Once one has that information, ways of applying nitrogen fertilizers that reduce the amounts of methane production from rice paddy or nitrous oxide production from other crops can be developed.

Dr Seghal (Delhi University)
You suggested that antibiotics could be used to lower the production of methane-ammonia from cattle as well as from rice paddies. I wonder if that is a relevant

suggestion at all because we know that animals and the microorganisms share a symbiotic relationship. If you destroy one of them, you are going to destroy the other also.

Professor Conway
It does not carry such a risk but we need more research on that. The biggest risk is that bacteria would rapidly develop resistance to antibiotics.

Amrita Achanta (Tata Energy Research Institute)
Given the paucity of and difficulty in obtaining data at the field level (for crop modelling studies) as well as the difficulty in validating models at individual sites, could you suggest alternative methodologies for estimating impact of climate change on production of major crops within a country? It is this question of scale—of projecting the results from the field to the entire country—that is the question.

Dr Warrick
There is no clear answer, no off-the-shelf methodologies one can apply to the problem. Given the experience in other countries, the right way to explore would be to see if one can develop a generic physiologically based model of crop growth, or else use a model such as the CERES wheat model and adapt that to local conditions. Many countries around the world are doing this.

Amrita Achanta (Tata Energy Research Institute)
The difficulty lies in obtaining field data and then in validating them so as to obtain meaningful results. So I wondered whether there was any method other than using a crop model.

Dr Warrick
There is no satisfactory solution.

Professor Conway
One lesson here is that there has to be much closer co-operation among all those who are engaged in this activity. The problem is too large for individual bits of turf. A close interaction that can feed the models back to the field work would be a great advantage for India.

Mr Hussain (Jamia Millia Islamia)
Dr Warrick said that a slight increase in temperature—about 1 °C or 1.5 °C—could decrease precipitation, and the overall impact on agriculture would be a reduction in yield and production in Europe, particularly in Britain. This is a gross

generalization; atmospheric circulation is not so simple. If there is a one-degree change in temperature, all the pressure belts will shift slightly northwards and the temperate cyclones that originate at around 45° north may move 48° north. In that case Wales and Scotland, which are predominantly pasture areas, may be very useful for the production of maize and other important cereals. The cropping pattern will change, but I doubt whether production will decline—the matter needs to be investigated further.

Dr Warrick

I said at the outset that I was going to show you some results of some simple analyses, keeping everything other than temperature constant. We do not know that other changes will accompany a change in temperature. However, assuming everything else remains constant, one can start determining relationships and anticipate crop responses. Of course, in a regional picture of climate change there are bound to be changes in precipitation patterns, seasonal changes in temperature, intensity of rainfall, and number of rainy days. All these will impinge upon that crop as well as the potential productivity of other crops.

Professor Conway

You seem to have made an important distinction here between the yield per hectare and the total production in the country. That is important when thinking about India, because it is virtually impossible at the moment to look at the changes in production patterns that may occur: shifts, for example, from maize or wheat towards rice whatever else as a result of altered yields of individual crops per hectare. The total pattern of production in the whole country may not necessarily change.

J S Pandey (National Environmental Engineering Research Institute)

My experience with development of a forest ecosystem model based on the physiological factors that you suggested brought me in conflict with some of the experimentalists. The problem is that the experimentalists have their sets of data and they want a modeller to use the kind of data they have collected, the modellers want experimentalists to follow the parameter pattern set by themselves through a mechanistic processes. What would you advocate—modellers should follow the experimentalists or the experimentalists should follow the modellers?

Dr Warrick

In this debate there are really no clear distinctions between experimentalists and physiology-based modellers because modellers rely largely on experimental data. So there is a blending of the two, whether you like it or not. Secondly, whether one opts for an experimental approach or for a pure simulation physiological approach

depends on the questions that are being dealt with and the region to which the work relates. From many parts of the world you can get good results with simple empirical models, particularly in the tropics and sub-tropics, where rainfall has a more dominant effect than other climate variables. But such models are not suitable in many parts of the mid-latitudes where grain response is much more complicated and involves an interplay among many climate variables and crop growth.

Dr S Mukherjee (National Thermal Power Corporation)
Dr Warrick referred to the trade-off between the beneficial impacts of carbon dioxide and the impacts of temperature rise. But if you look at the earth's history we had a period when a similar situation did exist. I am referring specifically to the carboniferous period when the concentration of carbon dioxide was slightly high and was immediately followed by a large-scale marine transgression. Sea level did rise a little bit and half of the world was submerged. Are such past climatic conditions taken into consideration during simulation and impact assessment studies?

Dr Warrick
I do not know of anyone who has. Extrapolating from conditions that prevailed long ago in the past seems a bit difficult. Of course it has applications in the climate analysis area but not, as far as I know, in the crop modelling area.

Dr S Mukherjee (National Thermal Power Corporation)
During the carboniferous period, a very large-scale plant growth was immediately followed by a large-scale marine transgression also. Both temperature and concentration of carbon dioxide were high during those periods; perhaps not as high as what we are talking about but certainly very high.

Dr Warrick
The interaction between the two is quite evident. It becomes clear in experiments but only during the past five years or so that the interaction between climate change and increased carbon dioxide has received scientific attention. In fact, this topic was considered to be a large gap in research.

Dr Jagdish Bahadur (Department of Science and Technology)
Already there is a controversy about organic and inorganic forms of fertilizers. I would like to draw the attention of the house that as early as in 1930, crop yields per unit area in India and the West were comparable but now there is a big difference because of the inputs. The solution is to make agricultural production system more energy efficient; otherwise, there would be a corresponding increase in agriculture-related pollution. India has a large population engaged in agricultural production

but with less than 2.6% of the world's land we are already producing more than 10% of the total food production of the world, and providing employment to more than 50% people in the field of agriculture.

Professor Conway
I agree that the question of efficiency is a central one. Efficiency can be attained through different means, whether it be inorganic or organic agriculture. Bio-engineering and bio-technology also have a role to play; you can create new kinds of plants that are much more efficient at this conversion. Losses of nitrogen in tropical and sub-tropical conditions are considerable—only something like 50 to 60% of nitrogen is taken up by plants under dry conditions; in paddies, nitrogen uptake is down to 30 to 40%. The losses are enormous and we have to get the research going to increase efficiency.

Dr V K Sengupta (Plant Physiology Division, Indian Agriculture Research Institute, New Delhi)
Some of our winter crops respond differently to high CO_2. For example, wheat plants grew more under high CO_2 only when the temperature is high (above 10 °C). If the temperature is below 10 °C, the plants do not respond to high CO_2. This means the plants at the reproductive stage will not respond to high CO_2. It is only at initial vegetative stage that the response to CO_2 is high. Thus if the temperature increases along with the carbon dioxide, it may have a better effect on wheat growth especially in Northern India.

Mr Satish Chandra (National Institute of Hydrology)
Dr Tewari has presented a very good account but I am not sure whether the results that have been indicated are qualitative or quantitative. He made a reference to plot studies. Have some studies been done on the watershed escape and whether these studies assess the effect of different species of forests, orchards, floods, and grasslands on CO_2 absorption and productivity?

Dr Tewari
The data are based on 303 preservation plots. I have indicated that they were laid in 1905 onward. Of course they do not cover all sub-types of forests. Out of 198 sub-types of forest, the data cover hardly about 150 or so. But then inside within the preservation plot, all species, whether grass, herbs, shrubs or trees are studied. The data are drawn over varying periods: some have covered more than 80 years; others could cover about 50 to 70.

Mr Mandalia (Unesco)

Of all the papers presented this morning, Dr Tewari's paper seemed to indicate to us that global warming has a definite effect on forestry. The rest of the papers were not as conclusive. Does climate change really have such an immediate and visible effect on forestry? Secondly, the high-yielding varieties of rice: do they mean more methane in the atmosphere? Does more methane have any effect on rice yields?

Dr Tewari

The data are based on more than 70 years. The studies now indicate that after 1975 the changes have been very abrupt, some of the species totally disappearing from a given area. For example, *Lantana* was more or less unknown in the high altitudes. But now whether in the Terai area in the foothills of the Himalayas or elsewhere, it has spread almost everywhere. Regeneration of all the tree and shrub species has been inhibited. We studied the diadific factor but it certainly was not responsible. We studied the temperature too. Certain plants occur in the arid area, some in the semi-arid area, some in the moist area, and others in the evergreen area. But that change has not been so abrupt. So the indication is that a perceptible change has occurred. Certain valuable species have totally disappeared. *Texas vacata*, for instance, which was once known to occur, just as the *Lantana* is now occurring, all over the forest areas of the Himalayas. But now *Texas vacata* is to be located only in a limited pocket and that also in limited numbers. That is why it has been listed as endangered species. Such observations certainly indicate that some brisk change has taken place. Since we do not find any perceptible change in the soil on analysis, probably the change is related to climate. Probably it is the climatic change that is responsible for certain species of the flora and the fauna to be endangered.

Dr R S Rana (National Bureau of Plant Genetic Resources)

Global warming, viz-a-viz the climate change, will also affect the incidence of diseases and pests. For example, if the temperatures do not rise in Northern India, say by February, we heave a sigh of relief that mustard, for instance, has escaped the aphid. Also, appropriate timings for sowing will also change. We advocate that wheat should be sown when the average of maximum and minimum temperatures comes to 20 °C. This happens around mid-November now but might move to end-December. Then the temperatures will start rising again, making the crop cycles very short. Therefore we will need new kind of genetic variability for crop improvement.

Professor Conway

That is a very important point. My own centre at Imperial College, the Centre for Environmental Technology, was able to show a number of years ago the impact of air pollutants on the multiplication rate of pests. It showed very clearly that greenfly

and aphid multiplied much faster under polluted conditions and caused worse problems.

Professor Subramaniam (Andhra University)
As Professor Menon and Dr Sikka pointed out, a lot of data on climate have been collected for the past 100 years, which offers a lot of scope for impact studies. For example, the impact of UV radiation on various crops: it is not very clear as to how much or what kind of impact it has on different crop seeds. Also, the impact of climate change on crop growth: for example, we have studied the influence of climate change on *Michaelia champaka* a flower crop in Visakhapatnam in Andhra Pradesh. We found that increase in temperature affects the quality and quantity of the flower crop. Similar studies are needed on horticultural crops. We have evolved a linear regression model on the impact of ambient temperature on milk yields and we found some kind of a correlation. What kind of influence it will have in other parts of India is not known. As to human beings, about 4000 cases of cerebrovascular accidents were analysed from the cases registered in hospitals in Patna and also in the South Patnam Hospital in Andhra Pradesh. It was found that climate change has an impact on human health, particularly in the area of cerebrovascular accidents. Certain species of fauna face extinction following a reversal in polarity of geomagnetic fields due to depletion of stratospheric ozone. Mortality and fertility of animals are severely affected by climate change. Lastly, there is a need for regional studies on the impact of enhanced greenhouse effect on individuals, particularly in India. (Recently, I came across a report on Queensland in Australia; similar studies are necessary.)

Dr Sharma (School of Environmental Sciences, Jawaharlal Nehru University)
If drinking water is disassociated from other water supply, particularly waste water, then waste water could be used by the industry. What difficulties in water management do you foresee for such a policy? In other words, by making a clear distinction between drinking water and other water-uses can we arrive at a more efficient use of water?

Mr Verghese
Drinking water in India, as perhaps everywhere else in the world, occupies first priority. Even irrigation schemes must reserve some water for drinking. That includes livestock too. The drinking water allowance we make in urban areas—the best is about 120 to 150 litres per person per day and in the rural areas only 40 litres—well below international standards. With any improvement in quality of life this quantity must increase. It is not only for drinking but for washing and for other domestic needs. It is going to be increasingly difficult to manage water supplies

because of the seasonality of the natural rainfall as well as whatever might happen in the future and the spatial variations. Ground-water is being used but in many places we face acute shortages and there is salination and contamination and so on. With these problems, water is going to be an extremely important issue and there again questions of pricing become important because domestic water, is generally priced well below the economic cost and is heavily subsidized.

Mr Satish Chandra (National Institute of Hydrology)
When we look to the area of water the modelling that has been done is on a macro-scale. However, if we want to study the water resources, a finer resolution of the GCM has to be used. Only then would we be able to get a better indication on the distribution of the temperature increase, especially in India. For instance, a temperature rise in the south, where the land is rocky, would have a much greater effect. The floods and droughts will also have to be seen from that view. With regard to the melting snow, the increase in temperature will result in an earlier melting of snow which means that during the rainy season, the snow melt will not be available. The effect of receding glaciers will prove detrimental. What would be the temperature variation due to water bodies that are man-made? Would they also affect the climate of the region? As to the sea level rise, it is anticipated that the river congestion in the deltaic regions would be much more and the salt water intrusion would occur to a larger extent. It was mentioned that as a result of global warming, there would be more cyclones in the coastal belt, which will affect the extent of salt water intrusion, but we do not know to what extent this would be important.

Commander Bahl (Maritime scholar)
We could have some system by which instead of using filtered water for the flush system we could use unfiltered water thereby making available more filtered water to be used as drinking water.

Mr Verghese
Filtered water should certainly not be wasted but perhaps there are problems of construction. You would need to have separate systems of pipes and so on, and there is always the danger that the wrong tap might be turned on; one might drink unfiltered water and flush the filtered water. The other problem is that the flushing cisterns are available only to a very small percentage of the population: in the rural area, practically not at all; in the urban areas, to a very limited extent. Only about a third or a quarter of our cities are sewered. With the urban population expected to rise to about 400 million over the next 20 years, the availability of 'modern' sanitation and sewerage facilities is going to be reduced sharply. So experiments are under way to develop low-cost sanitation models for flush latrines that use only two

litres of water which you flush instead of about ten. However, our water budgeting is heavily oriented towards agriculture. This is going to call for some amount of reconsideration and greater water-use efficiency in agriculture.

Member of the Audience
Some estimate that India has the potential to feed one billion. Dr Anil Agarwal stated that we could easily support even two billion. Does,it depend on how efficiently we manage our ecosystem?

Mr Verghese
There is a gap between theory and practice. The theoretical potential could be 20 billion although I hope we do not have to actually do anything of this order of magnitude. But the practical issues are irrigation, farming efficiency, systems and so on. I am quite certain that India could support much larger numbers than at present. Yields today are dismally low even in irrigated areas. The potential is enormous and India could be a net exporter of grain and agricultural products in due course but I am not sure whether the figure of 20 billion is realistic.

Member of the Audience
We have to delink the issue of drinking water from climate change because there are other factors or other dimensions that need to be considered. Increasing pollution of our water resources is one of them. The Government of India has made it a social objective to supply water to every individual. The only way this could be done is to pipe mineral water from the Himalayas because there are a lot of difficulties of recycling and water treatment.

Member of the Audience
The Himalayas, including the Tibetan plateau, have a tremendous influence on the climate in regional global terms. There have been international experiments like Alpecs on the Alps by WMO and on Karakoram by the Royal Geographical Society. These are the international experiments and efforts to study the mountain systems. Are there any international efforts to study the Himalayas?

Dr Verghese
ICIMOD (International Centre for Integrated Mountain Development) in Kathmandu has a very broad charter. It could perhaps take up some of these issues. However, the key to this is co-operation between China and India, and India and Pakistan. Indian leadership is vital because we are right in the middle of it all.

Energy demand and supplies: Britain and the European Community

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Compared with most industrialized countries, the UK is well endowed with energy resources. Even after coal ceased to be the mainstay of British industry, the discovery of large reserves of oil and gas under the North Sea has allowed the UK to be self-sufficient in energy since 1975. The rate of growth of energy demand has declined substantially since the oil crisis. As the basic needs of the population have been met and with basic infrastructure in place, increased levels of energy consumption may not be necessary to generate further economic growth.

Table 1 shows projected carbon dioxide emissions from energy use by different regions of the world. This table, drawn from the report of IPCC (Intergovernmental Panel on Climate Change) Response Strategies Working Group, places the European situation in the global context. Carbon dioxide emissions from developing countries are projected to increase by a factor of four between 1985 and 2030. Over the same period, emissions from the industrialized countries could approximately double. Although developing countries would expand their share of global emissions from 26% of 44% under this scenario, per capita energy consumption by 2025 would be just a quarter of the present level in the industrialized world.

This paper does not discuss the global equity questions raised by the IPCC projections but focuses specifically on the energy demand-supply situation in one industrialized country. The paper begins with a description of energy supply and demand patterns and their consequences for carbon dioxide emissions, then moves on to look at energy policy, prospects for future energy demand, and the size of the task involved in meeting the environmental targets that Britain has set itself. The role of EC (European Community) has come to be of great importance for British policy in this area and the wider European situation is discussed briefly.

Energy use and carbon dioxide emissions

It is illuminating to examine the historic links between economic growth, energy demand and carbon dioxide emissions. Figure 1 illustrates the main trends in the

Table 1. IPCC (1990) reference scenario for carbon dioxide emissions (billion tonnes carbon per year).

Region	**1985**	**2000**	**2010**	**2025**
Global Total	5.15	7.30	9.08	12.42
Developed (*per capita*)	3.83	4.95	5.70	6.94
	3.12	3.65	4.02	4.65
North America	1.34	1.71	1.92	2.37
Western Europe	0.85	0.98	1.06	1.19
OECD Pacific	0.31	0.48	0.55	0.62
Centrally Planned Europe	1.33	1.78	2.17	2.77
Developing (*per capita*)	1.33	2.35	3.38	5.48
	0.36	0.51	0.64	0.84
Africa	0.17	0.28	0.45	0.80
Centrally Planned Asia	0.54	0.88	1.19	1.80
Latin America	0.22	0.31	0.42	0.65
Middle East	0.13	0.31	0.44	0.67
South and East Asia	0.27	0.56	0.89	1.55

Source: IPCC Working Group 3, Energy and Industry Sub-Group.

UK primary energy demand over the period 1947-1990. It shows steady growth in energy demand until the 1970s, followed by stagnation in the wake of the oil crises. Energy demand recovered during the 1980s and now stands at the same level as in 1973. There has been a movement away from coal as first oil, and then natural gas, became available. Non-fossil energy sources, namely nuclear and hydro-power,

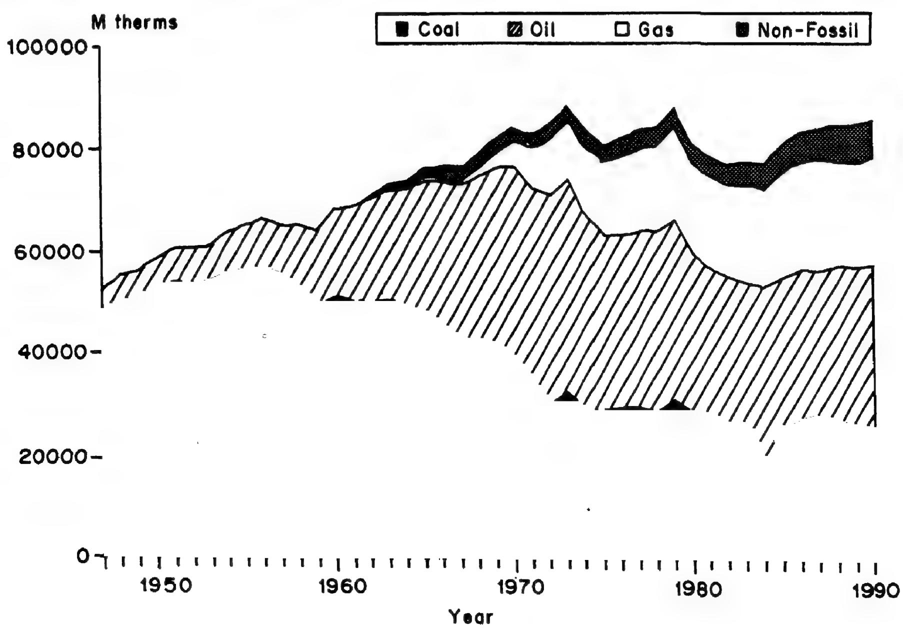

Figure 1. UK primary energy demand by fuel.

make only a small contribution to the overall energy balance. Figure 2 presents the associated carbon dioxide emission trends.

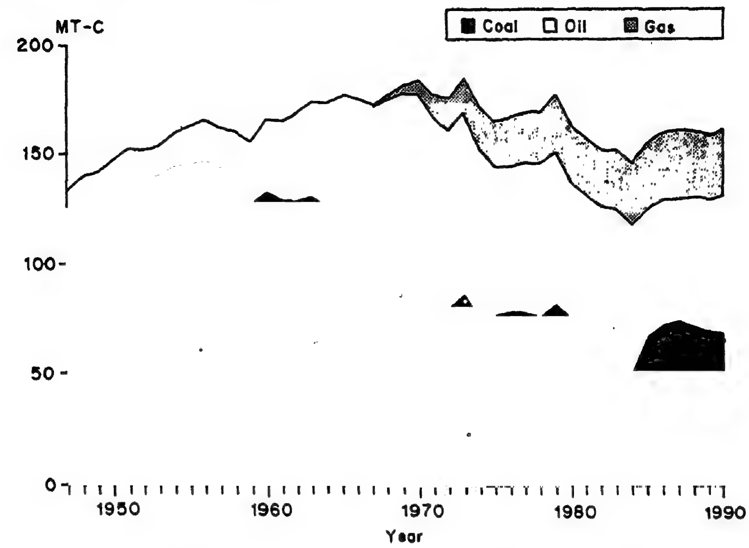

Figure 2. UK carbon dioxide emissions by fuel.

The period 1947-90 may usefully be broken into four phases.

Phase 1, 1947-57, covered Britain's immediate post-war recovery. Economic growth was brisk and a modest improvement in energy efficiency took place. Coal remained the dominant fuel throughout this period and, consequently, carbon dioxide emissions and energy use grew on a 1:1 basis. Carbon dioxide emissions increased at 2% per year.

During 1957-73, *Phase 2*, economic growth accelerated slightly, while the rate of improvement of energy efficiency increased markedly. Coal was substituted first by oil imported from the Middle East and then, from 1967 onwards, by natural gas from the North Sea. This progressive move away from carbon-rich fuels led to the decoupling of energy growth and carbon dioxide emissions. The introduction of nuclear power in the mid-1960s played a fairly minor role in moderating the growth of carbon dioxide emissions.

The 1973 oil crisis and its aftermath had profound effects on carbon dioxide emission patterns. Economic growth slowed to 1.1% per year. At the same time, the rate of improvement in energy efficiency accelerated, leading to an 11% decline in energy use. Much of this was due to plant closures in sectors such as steel during the 1979-84 recession. In the early 1980s, the structure of economic activity in the UK shifted significantly away from manufacturing industry towards the less energy intensive service sector.

In terms of carbon dioxide, the decline in energy use in 1973-83 was partly compensated by a halt in substitution away of coal. The use of oil for electricity generation declined as did the substitution of oil and gas for coal in industry. The

continuing penetration of natural gas in all sectors other than transport allowed carbon dioxide emissions to decline by 20% between 1973 and 1983.

Since the early 1980s, the British economy has grown at 3% per year, while the rate of improvement of energy efficiency has fallen back to the longer term historical average. At the same time, the penetration of natural gas has slowed. The carbon dioxide/energy ratio is falling relatively slowly and total emissions are increasing at about 1.7% per year, almost as much as in the 1947-57 period.

This description illustrates the transition which Britain has made from a country dominated by manufacturing activity, and almost exclusively dependent on coal, to one where energy consumption and carbon dioxide emissions have become decoupled from economic growth. Future changes in emission patterns are discussed below.

Underlying developments in energy use over the last 30 years have been two long-term trends. One is the gradual electrification of the UK energy economy. The proportion of final energy demand accounted for by electricity rose from less than 7% in 1960 to 15% in 1990. A third of UK primary energy is now transformed in power stations.

There have also been changes at the sectoral level. Transport energy demand, which is met almost exclusively by oil products, doubled between 1960 and 1990. The share of transport in final energy demand rose from 17% to 33%. In the 1960s and 1980s, the other growth sector was services where demand rose by 30%. By 1990, domestic sector energy demand was some 11% higher than in 1960. Industrial energy reached a peak in 1973 and, despite recovering in the latter part of the 1970s, is now a quarter lower than in 1960.

UK energy policy

The general objective of UK energy policy is to 'ensure that the nation's needs for energy are met both now and in the future in the manner which makes the best use of both energy and other resources'. Such a broadly stated objective can be interpreted in many different ways. During the 1970s, the Government intervened in energy markets in order to reduce dependence on hydrocarbon fuels. The general philosophy was known as 'co-co-nuke', i.e. support for coal, conservation, and nuclear power.

However, free market rhetoric took over as energy markets slackened in the 1980s. The central objective of energy policy became to 'remove market distortions where possible or otherwise seek to ensure that the energy market operates as nearly as possible as a free market'. The gas and electricity industries (apart from nuclear power) have been privatized. If re-elected, the Conservative Government would privatize the coal industry. Reflecting the changed relationship between Government

and the energy industries, the Conservatives will disband the Department of Energy if they win this year's election.

Associated with the free-market policy was a reluctance to publish forward projections of energy demand. It was believed that these would unduly influence the decisions of participants in the energy market. This reluctance has been the subject of criticism from international organizations, notably the International Energy Agency.

The climate change issue emerged when the Government was little inclined to exercise control over the activities of the energy sector. The attention of the energy industries has been focused on the privatization programme. The complexities of electricity privatization, which involved a complete restructuring of the industry, have been particularly time-consuming.

The irony of an environmental problem demanding regulatory intervention by Government emerging at the same time that the energy industries were being freed of Government control has struck many energy commentators. Innumerable seminars have taken as their theme 'regulation/strategy versus the market'. At the political level, this problem has partially been solved by the growing interest in 'market-based regulatory instruments', i.e. carbon taxes or tradable emission permits. The Government's argument now is that regulation and the market-based approach are mutually reinforcing. By 1989, the Environment Secretary could argue that 'the forces of regulation, price mechanisms and political ethics will intermingle to the point where it will be hard to tell where one ends and another begins'.

Notwithstanding the smooth presentation of policy, it is clear that British energy policy has undergone a major change of direction in the last three years. Climate change has emerged as the issue which brings a strategic focus to energy policy, much as high oil prices did during the 1970s. In particular, Britain's objective of stabilizing carbon dioxide emissions at their 1990 level by 2005, if other countries give similar undertakings, places great demands on the energy sector.

Forecasts of UK energy demand

Energy forecasting is not an activity with a distinguished record. Figure 3 shows the range of projected UK energy demand for 2000 (or 2005 for some of the latter exercises) in a series of forecasts published between 1976 and 1990. Scenario exercises carried out in the 1970s envisaged what are, in retrospect, extraordinarily high levels of energy demand. Later, demand projections fell progressively, led primarily by independent researchers. After the hiatus in energy forecasts during the 1980s, a recent burst of activity has been stimulated by discussions about future carbon dioxide emissions and possible policies to ameliorate climate change.

Figure 3 underlines the fact that long-term energy forecasts need to be treated with some care. Changes in policy, unexpected political and economic developments,

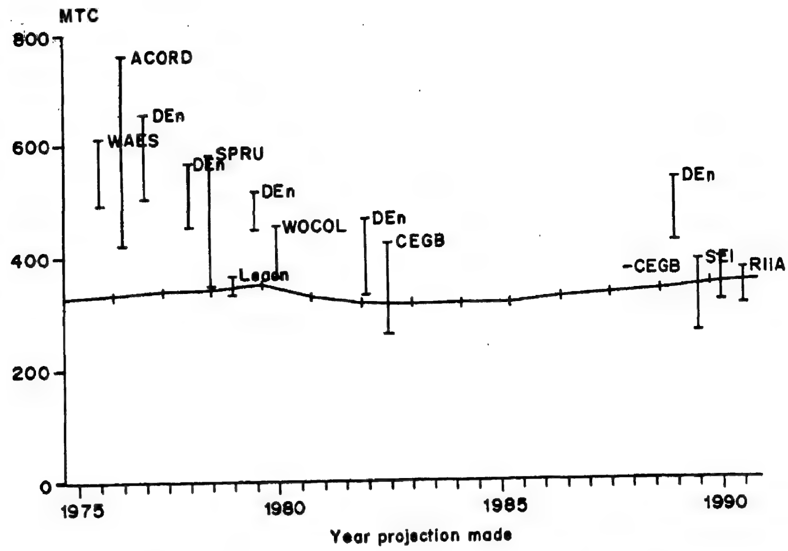

Figure 3. UK energy projections for 2000/2005.

and simple failure to take account of all the relevant factors can easily lead to huge divergences between forecast and out-turn energy demand. Recognizing this fact, it has become customary for those making energy projections to describe their work as scenarios rather than forecasts. A projection of energy demand extrapolating historic trends is now a 'business-as-usual' scenario.

Table 2 compares the results of five recent 'business-as-usual' energy scenario exercises for the UK. The first is the UK Department of Energy's submission to the IPCC in 1989. The Department produced six scenarios covering different assumptions about oil prices and rates of economic growth. Carbon dioxide emissions were projected to rise 11-41% by 2005 and 18-98% by 2020. Two scenarios

Table 2. Recent UK 'business-as-usual' carbon dioxide forecsts scenarios (million tonnes of carbon).

			% increase	
Year	2005	2020	2005	2020
1990 Baseline	160	160	-	-
Dept of Energy (1989)	178-225	188-316	11-41	18-98
Dept of Energy (central growth)	204-212	234-250	28-33	46-56
Science Policy Research Unit (1990)	175	187	9	17
Stockholm Environment Institute (1990)	182	N/A	14	N/A
Royal Institute for International Affairs (1991)[a]	182	238	14	49
Dept of Energy (1992)	166-200	188-284	4-25	18-78

[a] RIIA projections are for 2000 and 2030 respectively; estimates other than the Dept of Energy have been adjusted to take account of differences in the methodology for estimating emissions.

which reflected growth at historic levels led to emission increases of 28-33% by 2005 and 46-56% by 2020.

These projections were greeted with outrage by environmental groups. They appeared to put any ambitions to achieve the Toronto target of a 20% reduction in carbon dioxide emissions by 2005, or even an emissions stabilization, beyond reach. However, three independent studies produced around the same time projected much lower increases in carbon dioxide emissions—9-14% by 2005.

The difference between the Department of Energy's scenarios and those of the independents is partly explained by the different methods used. In late 1991, the Department of Energy released a brief summary of a more recent set of scenarios. The full results will be published later in 1992. These show estimates of future carbon dioxide emissions lower than those published earlier. The projected emission increase by 2005, 4-25%, is roughly compatible with the independent forecasts.

Figures 4 and 5 compare the Department of Energy's 1989 projections of final energy demand with those of one of the independents. Figure 4 shows that both ıe SPRU's (Science Policy Research Unit) 'business-as-usual' scenario and the)epartment of Energy's projections envisage a substantial growth in electricity .emand. However, there are great differences in projected oil demand.

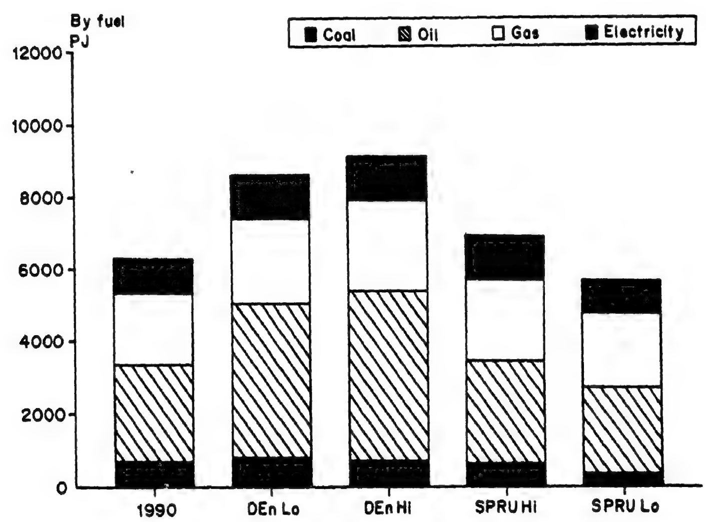

Figure 4. Projections of final energy demand (by sources).

Figure 5 shows that SPRU has made lower estimates of future energy demand in each of the main sectors of the economy. However, most of the difference between the SPRU and Department of Energy scenarios is accounted for by the projections of industrial energy demand. The Department of Energy anticipated that industrial energy demand would increase by approximately two-thirds between 1985-2005, while SPRU expected little expansion. This illustrates that industry is one of the most difficult sectors to forecast successfully.

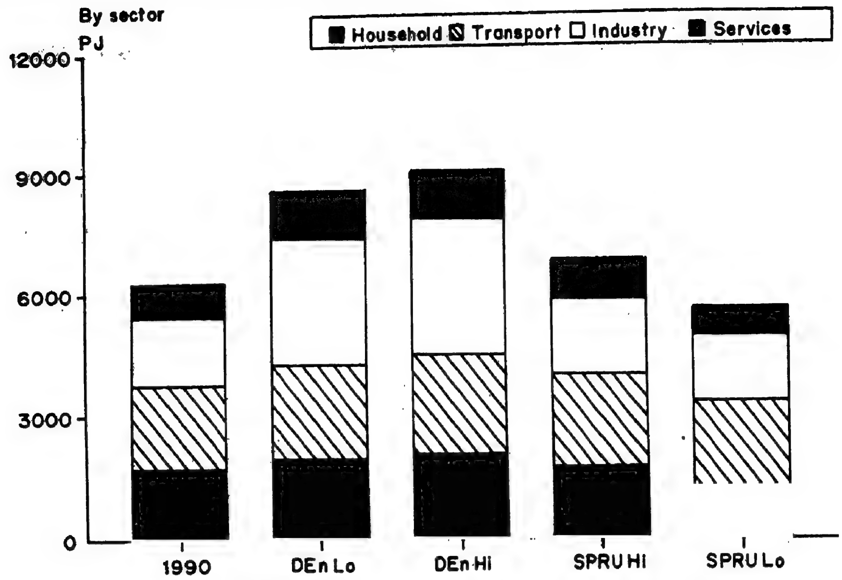

Figure 5. Projections of final energy demand (by sectors).

Recent developments in the electricity supply industry may partly explain the reduction in the Department of Energy's emissions projections. When the first set of projections was made in 1989, the process of electricity privatization was barely under way. Between 1989 and 1991, a massive re-alignment of the industry's investment plans took place. This was driven mainly by the criteria that private investors use to judge the profitability and risk of investment. Nuclear power stations were pulled out of the privatization in November 1989 and plans to build four new nuclear power stations were put on ice.

Plans to build new coal-fired stations were also abandoned, again because of high capital costs and long construction times. The EC has rescinded a Directive restricting the use of natural gas in power stations and, since 1989, firm plans to build about 10000 MW of gas-fired plant, based on combined cycle designs, have emerged. A further 8000 MW are being considered. These investments will reduce carbon dioxide emissions because of the high efficiency of the new stations (about 50%) and the low carbon content of natural gas. Figure 6 illustrates one possible development of the fuel mix in the electricity supply industry over the next 20 years. A large displacement of coal is likely.

Prospects for the European Community

Britain's policies to curb greenhouse gas emissions are inextricably linked to those of the EC. The EC's policy objective is to stabilize carbon dioxide emissions at their 1990 level by 2000.

Table 3 shows the results of a set of carbon dioxide projections which the European Commission made in 1989-90. These show that, in a 'business-as-usual' scenario, EC emissions will continue to rise until 2010. If economic growth is high and oil prices are low (the 'driving into tensions' scenario), emissions could rise by

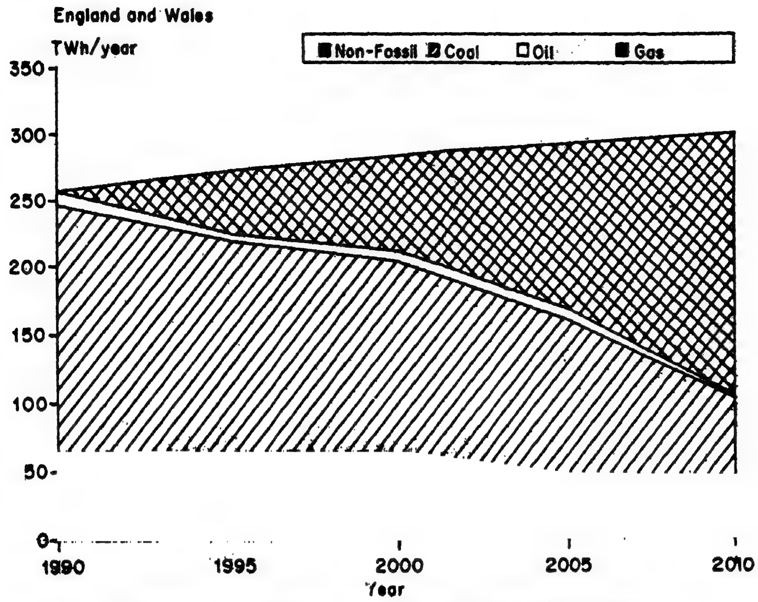

Figure 6. Projection of electricity supplied by type.

Table 3. European Community carbon dioxide projections (billion tonnes of carbon equivalent).

Scenario	1990	2000	2010
Business-as-usual	2.8	3.0	3.1
Driving into tensions	2.8	3.4	3.5
Sustaining high economic growth	2.8	3.1	2.4
High prices	2.8	2.7	2.1

Source: European Commission

21% during the 1990s, making stabilizing a difficult task. Even if strict regulatory measures aimed at improving energy efficiency are used (the 'sustaining high economic growth' scenario), emissions stabilization cannot be achieved until around 2005. It is only with the assumption of substantial fiscal measures (the 'high prices' scenario) that the target of stabilization by 2000 appears possible. This analysis supports EC proposals for a carbon/energy tax set at a level of $10 per barrel of oil. EC policy is discussed further in the paper 'Policy and awareness in the UK'.

Achieving reductions in greenhouse gas emissions

The projections described suggest that the UK will need to reduce its 'business-as-usual' carbon dioxide emissions by at least 10-15% in order to guarantee meeting its stabilization objective by 2005. All agree that energy efficiency will play the largest role in securing emissions reductions.

Figure 5 shows two SPRU scenarios for 2005. The first is 'business-as-usual', while the second is based on the assumption that all cost-effective energy efficiency opportunities are taken up. Under this scenario, carbon dioxide emissions would decline by about 10% by 2005. However, market barriers, such as lack of information, lack of access to capital, and unhelpful tax structures, impede the take-up of cost-effective efficiency measures.

Policies will be discussed during the third day of the symposium in the session on Responses. However, the following important features of the UK energy system indicate the problems that policy needs to address:

- Almost half of the UK housing stock was built before 1944 and has very poor standards of insulation. The potential for cost-effective energy saving in this area is very large. Only a fraction of the housing stock is demolished each year and the refurbishment of existing houses and heating systems will be essential if energy use in this sector is to be reduced.
- The fastest rate of growth of energy demand is in the transport sector. While technical changes could improve fuel efficiency considerably, there will be pressures during the 1990s to constrain the use of private motor vehicles. This will be driven partly by other environmental constraints, e.g. congestion and the impacts of new road-building.
- The privatization of the electricity supply industry has enhanced opportunities for industry to invest in CHP (combined heat and power) systems. CHP reduces carbon dioxide emissions because it is more energy efficient and because it often acts as a vehicle for the substitution of gas for coal.

There are fewer supply-side options to limit carbon dioxide emissions in the short term. The electricity industry is constructing low-pollution combined cycle gas turbine plants at the maximum rate possible. The fate of the nuclear industry is in the balance pending the completion of a review by the Department of Energy, which will be completed in 1994. A change of Government this year would almost certainly spell an end to nuclear development. Ministers in the present Government have indicated that nuclear power will be given the go-ahead only if it proves itself viable in the market-place. Most current estimates put the cost of nuclear power at 5-6 pence/kWh while some new fossil stations can deliver power at less than 3 pence/kWh. The EC's proposed carbon tax would not bridge this gap. The Department of Energy is conducting a study of the external costs of different forms of electricity generation which might influence the outcome of the 1994 review.

The Government is currently encouraging renewable energy through a quota applied to electricity suppliers and a levy on fossil fuel-based electricity. The aim is to have 600 MW of capacity in place by 2000. It has been suggested by ministers

that 25% of Britain's generating capacity could come from renewable energy in the longer term. Tidal and wind energy are promising options in the UK, though resistance to the development of many sites on local environmental grounds is likely.

The future for energy demand and supply in the UK

For the UK, energy consumption is no longer seen as a necessary accompaniment to continued economic growth. Policy attention has shifted from the need to secure energy supplies and build up infrastructure towards a desire for freer energy markets, greater efficiency (both technical and economic), and reduced environmental impacts. Though some might argue that the pendulum has swung too far, energy security has been eclipsed by other concerns. Regardless of developments at the global level, the UK and the EC are likely to pursue policies that will result in a flat or decreasing level of energy demand and hence greenhouse gas emissions. The application of measures to secure this objective may be no easy task, but it will be a central priority during the 1990s and beyond.

Energy perspectives in the developing countries

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At the outset it should be said that what is put forward in this brief paper is not necessarily representative of all the developing countries because we are dealing with fairly diverse situations depending on whether a country is an oil importer or an exporter, its economic structure, the level of income, and so on. But there are some generic issues that are of global concern and an attempt has been made to put them forward as briefly as possible.

A background of the global situation with regard to energy use and the place of the developing countries is provided in Table 1. This is just an overall picture, which gives us a perspective of what we are confronted in general terms with as far as developing countries are concerned. As would be noticed, we have, in this table, information on energy and economic activity by national income, for different countries. This table is from a paper that Prof. John Holdren and this author recently presented as the theme paper on energy at the conference on ASCEND 21 (Agenda of Science for Environment and Development into the 21st Century), held in Vienna and organized by the International Congress of Scientific Unions (of which Prof. M G K Menon is the current President).

If we look at the three income groupings included in this table and population by billions—the actual numbers are not as important as the percentages—61% of the world's population is in the poorest category, 16% in the intermediate, and 24% in the richest. If we look at the corresponding distribution of GNP (gross national product), it is 6%, 8%, and 86% respectively. Now these are facts that are well-known, but they are important in looking at the energy prospects and the overall energy perspectives that apply to different parts of the world, because there is a major limitation that is inherent in the levels of income that different countries are confronted with.

It may be observed from Table 1 that figures on energy use are divided between industrial energy forms and traditional fuels. As far as the poorest countries are

Table 1. Distribution of energy and economic activity by national income.

	Country grouping by 1988 GNP/person					
	Poorest (<$1000)		Intermediate ($1000-4000)		Richest (>$4000)	
population, billions	3.1	(61)	0.8	(16)	1.2	(24)
GNP, billion 1988 US dollars	1100	(6)	1500	(8)	16400	(86)
Industrial energy use, TW	1.6	(14)	1.1	(10)	8.5	(76)
Traditional energy use, TW	1.1	(73)	0.2	(13)	0.2	(13)
Total energy use, TW	2.7	(21)	1.3	(10)	8.7	(69)
Electricity use, trillion kWh/year	1.1	(10)	1.1	(10)	8.4	(80)
Electric generating capacity, GW	240	(9)	280	(11)	2030	(80)
Refinery capacity, million barrels/day	6	(8)	13	(18)	55	(74)
Average GNP/person (1988 US dollars)	350		1900		13700	
Industrial energy use/person (watts)	500		1400		7100	
Traditional energy use/person (watts)	350		250		200	
Electricity use/person (kWh/yr)	350		1400		7000	
Refinery capacity/person (barrels/year)	0.7		5.9		16.7	

Notes. All figures are for 1988. Parenthetical figures are percentages of category; totals may not add due to rounding.
Sources: Hughart (1979), Hall et al. (1982), World Bank (1983), Goldemberg et al. (1987), World Bank (1990), Population Reference Bureau (1990), and authors calculations.

concerned, they consumed, in 1988, about 14% of industrial or conventional fuels as opposed to traditional fuels totalling 73%. In comparison, the richest countries, which constitute 24% of the total population of the globe, consumed 76% of the total industrial energy forms used in the world and only 13% of the traditional fuels used globally. There is, therefore, not only a major disparity in the total consumption of energy, combining both conventional or industrial fuels as well as traditional fuels, but also a major difference in the mix of energy resources used between these different groups of countries. Given the growing scarcity of capital resources for energy investments in the developing countries, it is unlikely that unconstrained increases of energy consumption in the poorest countries would take place in the next one or two decades. A good example of this reality is the situation existing in India, where targets for public-sector-funded capacity additions in the power sector are having to be scaled down, because the capital resources required to meet the original targets in the Eighth Five Year Plan cannot be mobilized.

The picture of electricity use also requires close attention. It would be seen that the poorest countries of the world consume about 10% of the total electricity used

globally, the intermediate level countries another 10%, and the richest countries the balance 80%. Generating capacity in these three groups of countries corresponds closely to this distribution of consumption of electricity. Other data that are relevant and which are brought out in Table 1 pertain to average GNP (gross national product) per person, which varies from \$350 per capita in the poorest countries to \$13700 per capita in the richest countries. In assessing energy perspectives globally in general and the developing countries in particular, we must keep in mind the existing disparities that characterize income levels and hence the economic ability of countries to bring about structural change as well as alterations in energy use levels, which provide a clear basis for increases in energy consumption that are inevitable in the developing countries in the face of various constraints that they are currently struggling against.

In assessing actions to avert the threat of global climate change, we must not only evaluate the current or potential future levels of carbon dioxide emissions but the historical levels that have been established by different groups of countries in the past. The problem of climate change likely to be brought about by the greenhouse effect is a resultant of increased CO_2 concentrations in the earth's atmosphere, which have built up over a long period of time and are not merely the result of instantaneous effects taking place today. CO_2 is a stable gas, the build-up of which has cumulative impacts on the concentration of this gas in the earth's atmosphere. TERI (Tata Energy Research Institute) has established an extensive database for energy consumption in different parts of the world and if we look at cumulative emissions for the period 1870-1986, the picture is brought out very clearly (Figure 1).

Undoubtedly, the share of the developing countries would increase appreciably in the future, because increases in income levels and changes accompanying development are yet to take place in these countries. In fact, at TERI it has been

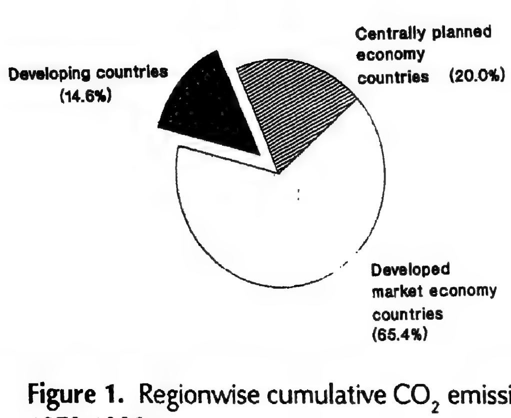

Figure 1. Regionwise cumulative CO_2 emission 1870-1986

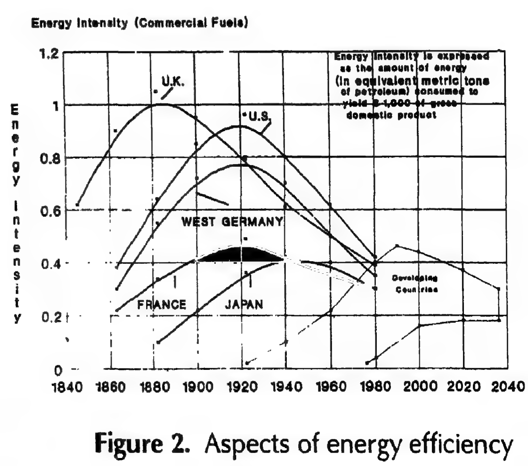

Figure 2. Aspects of energy efficiency

estimated that the share of cumulative emissions for different groups of countries up to 2010 would change marginally, for while the share of the developed market economies comes down from the current cumulative figure of around 65%, these countries would still account for about 55% of cumulative emissions up to 2010. The share of the developing countries at the same time would go up to a cumulative level of around 20%. Hence there is no substantial shift taking place in the responsibility for cumulative emissions in the next 20 years or so. There is currently an intense ongoing debate as part of the deliberations of the INC (Intergovernmental Negotiating Committee), which seems to ignore the historical perspective in responsibilities and actions related to climate change. In essence, one cannot ignore the fact that a small group of countries who have reached high levels of prosperity are responsible for a set of cumulative actions that have resulted in an increase of CO_2 concentrations in the earth's atmosphere. Consequently, there is a strong moral and logical basis for them to assume the burden of change that would bring about a reduction or at least a stabilization of CO_2 in the earth's atmosphere.

In the paper presented recently by Prof. John Holdren and this author referred to earlier, it was brought out clearly that the ratio of energy and GDP (gross domestic product) essentially increases as a country industrializes; only when it reaches a certain peak does it actually decline. This is brought out clearly in Figure 2. Undoubtedly, countries that industrialized later are able to achieve economic growth and development at lower levels of energy intensity than those industrialized earlier. It can be seen in Figure 2 that the United Kingdom, which was the first country to industrialize, reached a peak higher than other nations that followed a similar path subsequently; they reached lower peaks at later stages of global development. Consequently, the United States, West Germany, France, and Japan were able to industrialize with much lower energy intensity paths than the United Kingdom. This normally happens because those countries industrializing later are able to derive the benefits of technology improvements and efficiency gains that become available over time, but which were not available to countries that industrialized earlier.

As far as the developing countries are concerned, there are undoubtedly opportunities for development with higher levels of energy efficiency than the industrialized nations of the north found possible. But it is difficult to predict the actual path that most developing countries would follow, which could lie anywhere in the range indicated in Figure 2. Much, of course, would depend on the ability of the developing countries to mobilize capital for investments in energy efficient technologies and the manner in which these technologies could be made accessible to them. Hence, if the developed countries are to assume their moral responsibility for solving of global environmental problems, they would have to provide large transfers of capital for the developing countries and ensure freer access to energy efficient technologies.

In this context, a new interpretation of technology transfer becomes relevant and vitally important. For several decades now technology transfer has been seen as a process of providing know-how, equipment, and hardware from developed to developing countries. This arrangement viewed technology transfer and the infusion of new processes and production techniques as a technical fix. Adequate attention was not paid to the challenge of developing local capacity and infrastructure for adopting and maintaining new technology and equipment for overall economic benefit. Now that several developing countries have attained a high level of technical expertise and industrial skills, this aspect assumes even greater importance. Hence, in promoting technology transfer in the future, much greater attention would have to be paid to local capacity-building and the use of capabilities in the recipient countries in effecting appropriate technology transfer. In fact, a more relevant approach would be that of technology development, whereby the process of inducting new technologies is carried out as a partnership between the two parties concerned.

The paper by Holdren and this author referred to earlier developed scenarios for the future to see where the world was heading with regard to energy consumption and production. These scenarios are brought out in Table 2. The growth rates assumed in the 'business-as-usual' scenario are in keeping with trends established in various parts of the world since the first oil price shock of 1973-74. Projections for population were based on the work done by the World Bank, which clearly indicates that the bulk of global population increases would take place in the developing world, and a doubling of global population within a time frame of 50 years. Using the 'business-as-usual' approach, we estimated that energy use per person would increase in the industrialized countries to 7675 watts, whereas the developing countries would at best be able to treble their energy use per capita to a level of around 1880 watts in 2030. This would still leave a substantial gap between energy consumption levels in industrialized and developing countries. We then used a set of estimations developed by Dennis Anderson of the World Bank defining a set of scenarios that are based on efficiency gains somewhat more ambitious than the 'business-as-usual' scenario indicated in Table 2. The results from computations carried out according to this scenario indicate that the developed countries would stabilize their energy consumption at a level of 6285 watts per capita and the developing countries would be able to increase their consumption to around 2300 watts per capita.

The important implications of these figures, quite apart from the reduction in disparity that would come about, are related to total consumption of energy in 2030 that is thus aggregated. In the 'business-as-usual' scenario the world would consume 24.3 terawatts of energy in 2030. This is a staggering increase over the 1990 figures but what is even more significant is the fact that the developing countries would

Table 2. Conventional projections for use of industrial energy forms.

	Actual		Projection			
	1980	1990	2000	2010	2020	2030
Population (millions)						
Industrialized	1075	1158	1215	1260	1295	1315
Developing	3310	4085	5000	5900	6750	7575
Energy Use/person (watts)						
'Business as usual'						
Industrialized	7170	7255	7360	7465	7570	7675
Developing	615	770	965	1205	1500	1880
'Energy efficient' (Anderson)						
Industrialized	same		7435	7225	6325	6285
Developing	as above		950	1340	1720	2300
Total energy use (terawatts)						
'Business as usual'						
Industrialized	7.7	8.4	8.9	9.4	9.8	10.1
Developing	2.0	3.2	4.8	7.1	10.1	14.2
World total	9.7	11.6	12.7	16.5	19.9	24.3
'Energy efficient' (Anderson)						
Industrialized	same		9.5	9.5	8.5	8.6
Developing	as		4.8	7.9	11.7	17.5
World total	above		14.3	17.4	20.2	26.1

Notes. 'Business-as-usual' results obtained by extrapolating 1980-90 rates of increase in per capita use of industrial energy forms for industrialized and developing countries. One terawatt = 10^{12} W. Sources are World Bank (1990), Anderson (1991), and calculations by the author.

still not be at a stage where energy consumption per capita would get stabilized. Consequently, increases would continue in the global consumption even beyond 2030. As against this, the energy efficient scenario provides a somewhat higher level of energy consumption in 2030 but also establishes a level at which the developing countries may be able to stabilize their energy consumption by 2030. We are, therefore, confronted with a high level of energy consumption in both scenarios in 2030 beyond which increases would certainly not be sustainable. But the energy efficient scenario shows a narrowing of the rich-poor gap, which provides a reasonable basis for stabilization in the decades beyond.

An even more ambitious set of policies for ensuring sustainability has been developed in Table 3.

Based on this scenario, which assumes a more aggressive set of policies and adjustments that we developed, specific options were outlined whereby we postulated that developed countries would have to cut back on consumption substantially over a period of time and allow the developing countries to increase consumption somewhat faster. But we have also assumed efficiency gains for the developing countries based on certain reasonable assumptions so it is not as though the developing countries will continue on exactly the same path that was followed by countries that industrialized earlier.

The important thing to see is that the total energy per person in industrialized countries would have to more or less halve during this period, which would allow the developing countries to reach a level of 2395 watts, which would still leave a significant difference in consumption levels. GDP per capita is also shown in this table; total energy used would come down marginally over the earlier scenarios that we have developed. Now perhaps one way to bring this figure even lower would be to see that the developing countries are able to bring about greater efficiency gains and can attain the same level of economic growth without necessarily reaching the levels of consumption shown in this scenario.

This takes us to the next point that should be made and that is essentially the fact that if we want to bring about major efficiency gains in the developing countries,

Table 3. Efficiency-based scenario for narrowing the rich-poor gap.

	1990	2000	2010	2020	2030
Population (millions)					
Industrialized	1158	1215	1260	1295	1315
Developing	4085	5000	5900	6750	7575
Total energy per person (watts)					
Industrialized	7465	6125	5025	4120	3380
Developing	1085	1320	1610	1965	2395
GDP per person (1990 US $)					
Industrialized	15600	17230	19030	21026	23230
Developing	750	1220	1990	3240	5280
Total energy (terawatts)					
Industrialized	8.6	7.4	6.3	5.3	4.4
Developing	4.4	6.6	9.5	13.3	18.1
Total world	13.0	14.0	15.8	18.6	22.5

Notes. Population projections are same as for Table 2 (World Bank 1990). Energy figures include both industrial and traditional forms and come from the authors' calculations based on assumptions stated in text.

there would be an enormous demand for capital which, based on current reckoning, does not seem to be available. As a matter of fact, even if one follows a 'business-as-usual' type approach, today there is an acute scarcity of capital worldwide even in the Asian region. In fact at the last Asian Development Bank meeting it was clearly estimated and discussed that this particular problem is afflicting the countries of Asia, which was not necessarily the case earlier on. In other words, the situation in the Asian nations was never as acute as it is today. And, therefore, we feel that even to maintain current levels of economic growth may become very difficult, constrained as we are with capital for investments in the energy sector.

If over and above this picture we have to bring about improvements in efficiency in the developing countries, then there would be an even larger demand for capital.

Now, what is it that can be done? Firstly, the time has come when one has to think seriously in terms of some kind of a tax which would essentially not only be able to generate adequate resources for the kinds of shifts that we are talking about, but would also send the right signals to consumers in terms of quantifying the environmental impacts, and we are essentially talking of the global environmental impacts being produced as a result of consumption decisions. Now this would take enormous political will; it would take an enormous amount of negotiations but a shift in the positions taken is at least partly discernible in some countries of the world and one hopes that sooner or later international bodies like the UN would be able to accept and establish taxation levels as a norm that every country would follow in the years and decades ahead.

The other conclusion that we reach is essentially the fact that all this would require a new phase of technology development and R&D activities on several fronts in terms of developing new technologies, e.g. energy conversion. For instance, fuel cell technologies appear to be very promising and will bring about a quantum jump in the conversion efficiency for fossil fuels to electricity production, and I think here one needs a set of new partnerships because in the past we have seen technology development as merely a case of mechanical transfer from the North to the South. It must be submitted that the time has come when we need to conceive of and implement projects on a partnership basis between organizations in the North and the South.

As far as the developing countries are concerned there is no denying the fact that we have to find means by which we can raise resources internally. Our energy sector by and large is not very efficiently run and I think this would require some major institutional changes; it would require autonomy; it would require pricing decisions that are far more rational; and I think all of these should become part of the development agenda in the developing countries.

So overall, it must be said that what we are dealing with is really the formulation of some new paradigms of development and growth and particularly of energy use

and it is hoped that conferences like this and their proceedings would contribute to bringing about clarity in that direction.

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Energy demand and supply scenario in India

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This presentation covers energy demand and supply in India, and is divided into four parts: energy economy interaction; energy demand analysis; the MEDEE-S model (what the assumptions of the study are), sector-wise demand, and source-wise supply; and the ESCAP (Economic and Social Commission for Asia and the Pacific) study scenario development of the methodology, energy efficient scenario and fuel substitution included, and finally the conclusions that one can derive from it.

The Indian economy is agriculture-based: the share of agriculture in GDP (gross domestic product) was 33% in 1988-89, albeit lower than in 1950-51 when it was 55.4%. The share of industry, on the other hand, has steadily increased (Figure 1a). The past Five Year Plans emphasized a self-reliant economy with modernized and highly productive agriculture and industry. Substantial investments were made on the infrastructure including energy and transport. In the case of energy demand, non-commercial fuels such as firewood, animal wastes, and crop wastes are gradually being replaced with commercial fuels, as seen clearly in Figure 1b, wherein during the period 1950-51 to 1988-89, the share of commercial fuels went up from 26% to 56%.

An analysis of energy intensity, which is defined as energy consumption in the economy to the GDP for different commercial fuels, is shown in Figure 2 (for the period 1973-85). We find that coal is the dominant fuel, but energy intensity for all the fuels including coal, oil, and electricity shows an almost constant value of about 500 tonnes of oil equivalent per ten million rupees. Also, the energy intensity for coal has reduced over the years, whereas that for oil shows a slight increase.

However, the need to analyse energy demand is quite obvious on several counts including rapid growth in commercial energy and scarcity of financial resources (energy sector was allocated only 31% of the total plan outlays in the 7th Plan).

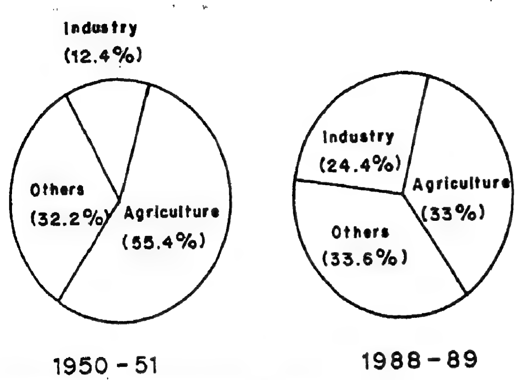

Figure 1(a). Percentage share in GDP (gross domestic product).

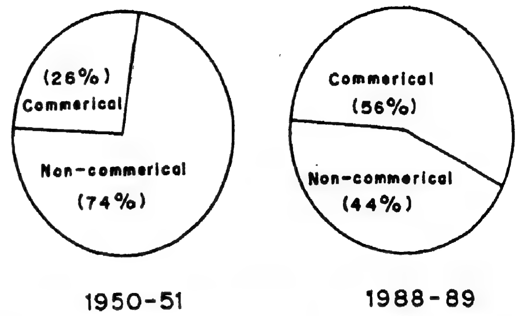

Figure 1(b). Percentage shares of sectors in energy demand.

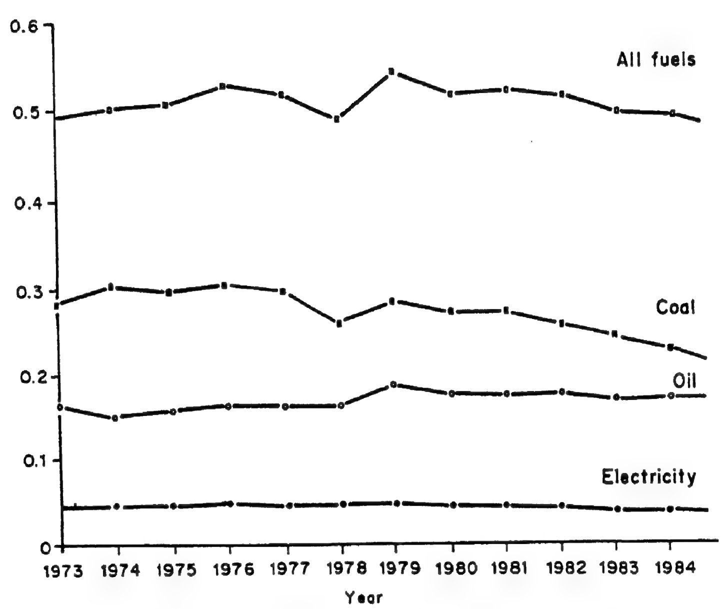

Figure 2. Energy intensity in the economy.

Several studies were undertaken in the past in the Indian context. These are listed below.

- Energy Survey of India Committee (1965)
- Fuel Policy Committee (1974)
- Working Group on Energy Policy (1979)
- Advisory Board on Energy (1985)
- Planning Commission Study (1989)

The Planning Commission study adopted energy demand estimates primarily on the basis of macro-economic projections and carried out comprehensive optimization exercises on the supply side. A recent study by the Planning Commission (1990) focused on the sectoral energy demand analysis using the MEDEE-S approach.

MEDEE - S approach

Features of the MEDEE-S approach are as follows:

- Energy demand is directly related to the end-use.
- The relationship between end-use activity levels and the macro-economic parameters is captured.
- The model permits analysis with reference to technological options and fuel-mix choices in major end-use activities.
- Structural changes in the economy can be studied.

In the case of Base Case assumptions, one finds that a high priority is accorded to reducing the overall energy intensity of the economy through appropriate structural technological changes, inter-fuel substitution, and energy conservation. Energy conservation is given importance, but it plays only a limited role. In the sensitivity analysis the factor has been taken into greater detail. The GDP growth rate is assumed to be 6% but keeps changing in the sensitivity analysis.

Sector-wise assumptions focus on agriculture. It is assumed that to reduce dependence on imported oil we will have an electrification programme: 12 million electric pump-sets and 5 million diesel pump-sets by the end of the century and 1.38 million tractors in operation. In the industrial sector, it is assumed that energy conservation, appropriate changes in the technology mix as well as fuel feed stock choices, and reduction in the growth of energy intensive industries will take place. In the transport sector, assumptions include a likely increase in the volume of freight traffic in the coming years and some changes in the inter-modal patterns. In the household sector, assumptions include patterns of income distribution and their impact on quality of life and fuel consumption; emphasis on rural electrification is also reflected in the demand for electricity in rural households.

Figure 3 shows the sector-wise growth of commercial energy. The results of MEDEE-S Base Case show that energy demand for different sectors would increase from approximately 84 million tonnes of oil equivalent in 1986-87 to 293 million tonnes of oil equivalent in 2004-05. Indian industry would continue to consume the bulk of commercial energy followed by the transport sector. The share of energy demand in the agricultural sector shows a decline from 8.7% to 4.8% with a minimum growth rate of 3.8%—the energy being consumed mainly for lift irrigation and agricultural operations in the form of electricity and diesel. The requirement for diesel for motorized fishing is also included. There is considerable potential (up to 30%) for energy conservation in the agricultural sector, and this can be taken into account in the sensitivity analysis. Sector-wise shares of commercial energy consumption in the study period show that share of transport and household sectors will increase more rapidly than agriculture and industry—the higher growth rate of 9.9% in energy demand in case of the household sector is nearly 2.6 times the

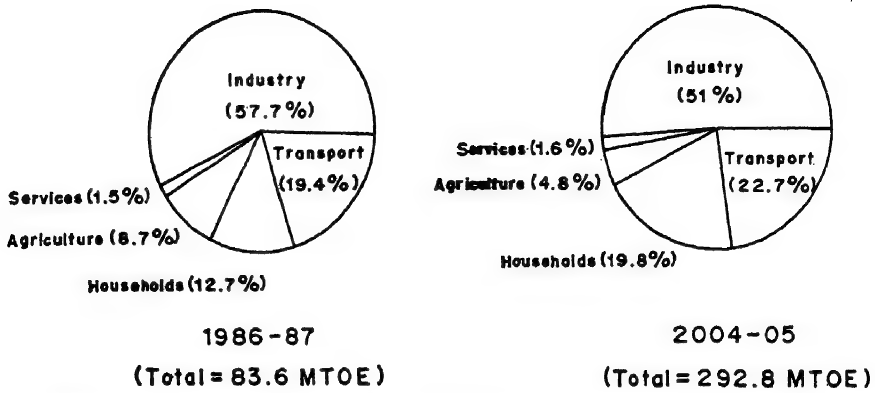

Figure 3. Sector-wise growth in consumption of commercial energy.

agricultural sector growth rate. This is mainly on account of the non-commercial energy being replaced by commercial energy in the domestic sector. Similarly the growth rates in the transport and services sector are also more than twice that of the agricultural sector.

The need for energy conservation has been built into the Base Case Scenario by an increase in the efficiency of end-use appliances. In spite of this, the Base Case Scenario for energy demand shows a 4% growth rate for the total energy demand from 1986-87 to 2004-05 (Figure 4). The growth rates of demand for coal, petroleum products, and electricity are much higher at 7.1%. However, demand for commercial energy shows a reduction of 0.5% in growth in this period, resulting in a decline in its share from 57.3% to 26% in 2004/05.

Figures 5-7 show the demand projections for coal, oil, and electricity respectively. The coal demand of 114 million tonnes of oil equivalent in 2004-05 excluding thermal stations' consumption would be mainly in the industry sector. Its share in the household sector is projected to increase steadily from 5.4% in 1986-87 to 17.5% in 2004/05. The oil demand projections excluding thermal power station

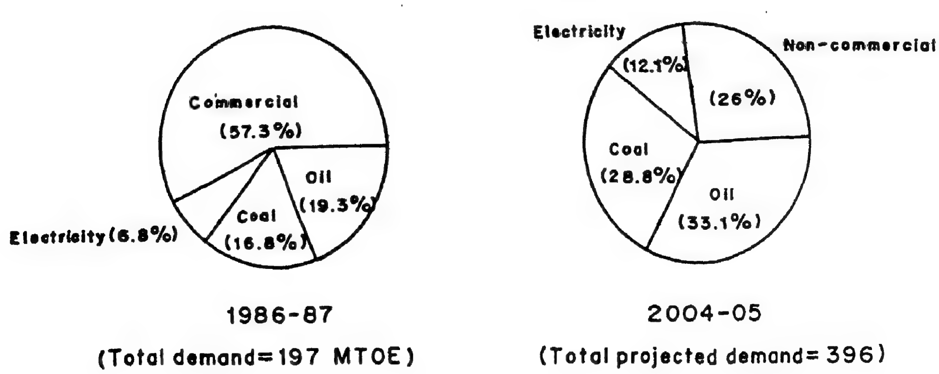

Figure 4. Sector-wise growth in energy demand.

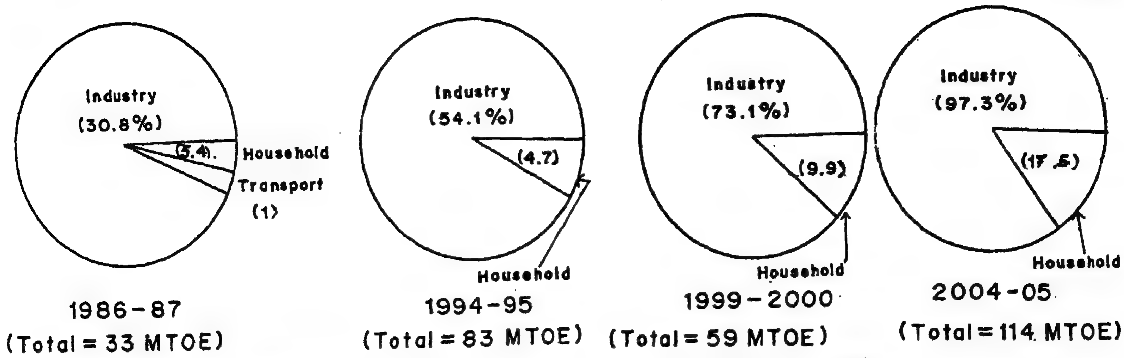

Figure 5. Growth in demand for coal. (growth rate=7.1%)

consumption show an increase from 38 to 131 million tonnes of oil equivalent, which is very alarming. This shows a growth rate of 7.2% in which the transport sector is the bulk consumer. Electricity consumption demand shows an increase from 13

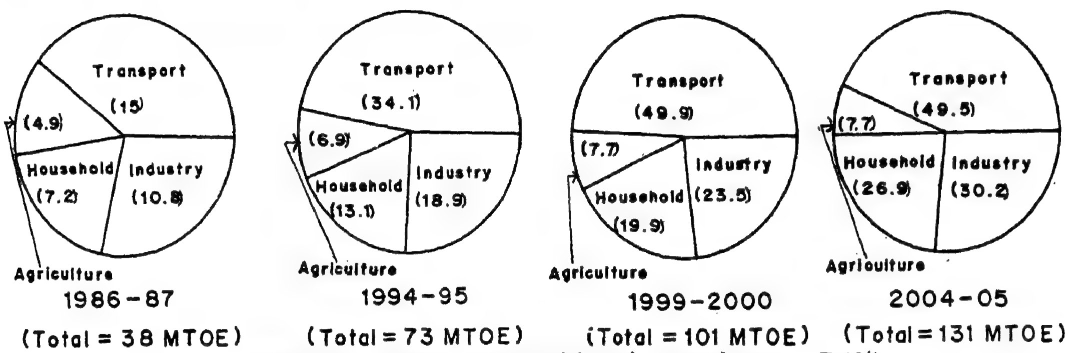

Figure 6. Growth in demand for oil. (growth rate = 7.1%)

to 48 million tonnes of oil equivalent with a growth rate of 7.8%. The trend for electricity demand in the household sector shows a greater share in total electricity consumption—13% in 1986/87 to 24% in 2045. The industrial sector shows a slight decline from 54% to 49.5% during the same period.

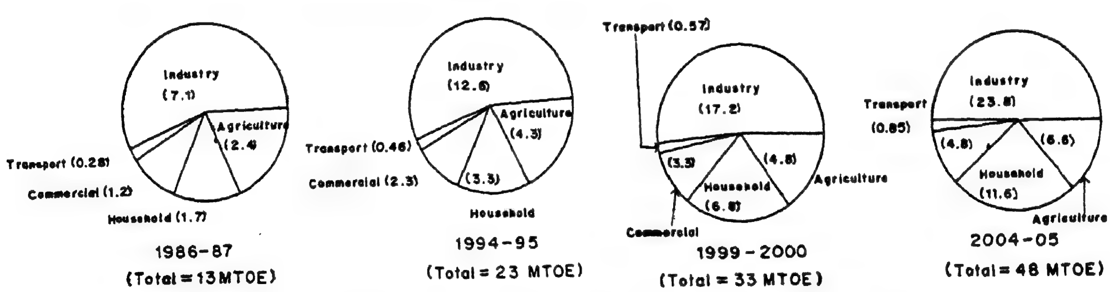

Figure 7. Growth in demand for electricity. (growth rate = 7.8%)

UN-ESCAP brought out a report in November 1991, titled 'Energy policy implications of the climatic effects of fossil use in the Asia-Pacific region', which contains results of the ESCAP study, policy options, and country papers.

The methodology of this study is based on three scenarios generated by considering 1986 as the base year and 2000 and 2010 as the future years. Environmental impacts of future energy supply and demand have been studied in

these two scenarios. The input data for the study have been derived from the various country reports. The energy balance sheet is derived from a modified ADB (Asian Development Bank) balance sheet. Databases for the MEDEE-S and the ESCAP are different. However, it is possible to use the MEDEE-S results and build up a similar scenario in India. The Planning Commission has started work on these lines. Three scenarios were developed.

Scenario 1 represents a 'business-as-usual' strategy, Scenario 2 represents a strong emphasis on improving efficiency of energy use and supply systems, and Scenario 3 represents a strong emphasis on improving efficiency of energy use, plus changing, where possible, to energy sources that emit little or no carbon dioxide. If one looks at the primary energies—coal and oil—and the results from the three scenarios, we find that for India the maximum reduction in energy consumption due to improvements in energy efficiency is assumed as 11% by the end of the century to 24% in 2010 with respect to the Base Case. Some of the major components of the strategy to reduce emissions would place a strong emphasis on energy efficiency improvements across all sectors, accelerating exploration and production of natural gas and hydro power.

In Scenario 1, the primary energy demand projections increase from 154 million tonnes of oil equivalent to 552 million tonnes of oil equivalent (Figure 8). A remarkable reduction in coal demand, amounting to 288 million tonnes of oil equivalent, is reflected in Scenarios 2 and 3. These scenarios also show a reduction in demand by 25% and 36% respectively. Similarly, the oil demand of 96 million tonnes of oil equivalent in Scenario 1 is reduced to 19.5% in Scenario 2 and Senario 3.

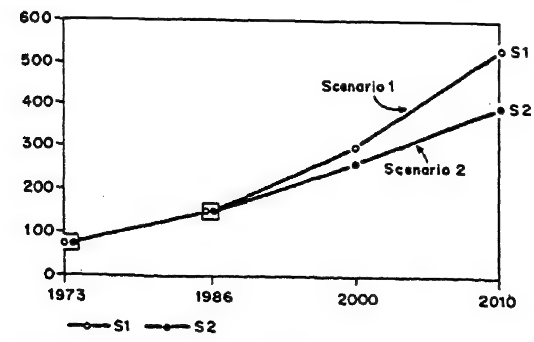

Figure 8(a). Primary energy (MTOE).

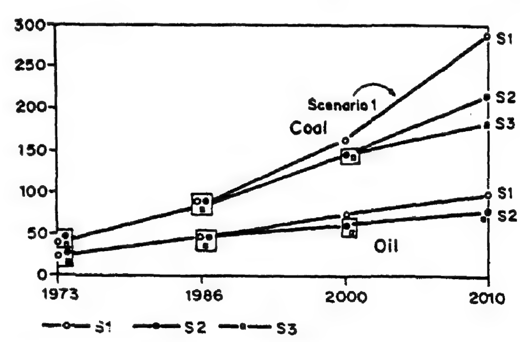

Figure 8(b). Coal and oil (MTOE).

Basically, the conclusions that we can draw from this study are as follows:

- The potential of fuel switching in reducing carbon dioxide emissions is much smaller up to 2010, compared to that of improved energy efficiency.
- The most effective strategy for limiting India's carbon emissions would involve improvements in energy efficiency.

However, having estimated the energy demands, the basic question remains: Can India raise the capital necessary to meet them?

Indo-British Symposium on Climate Change, 15-17 January 1992, New Delhi

India's viewpoints for climate change negotiations: analytical back-up

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When I was a theoretical physicist at University of California, Berkeley, I was rather impressed to see that the elegant concepts and theories that Heisenberg, Dirac, Schrodinger and other theoretical physicists worked with and talked about were the as those that the experimentalists worked with at the cyclotron at Lawrence Berkeley Laboratory or at the Linear Accelerator (mile long accelerator) at the Stanford University. At times, masses of the fundamental particles were first calculated by theorists within the four walls of their offices on paper or with the help of computers, and experimentalists tried to find them. At times, it was the opposite: the experimentalists measured very unusual events and the theorists had to explain them.

Professor M G K Menon, who has seen this partnership between theorists and experimentalists, has rightly emphasized the need for bringing together people who measure things and people who theorize and conceptualize; together, they can find new horizons.

I say this to invite partnership from some of those colleagues here who are measuring emissions of greenhouse gases from paddy fields or by livestock. I intend to present estimations of CO_2 emissions from India by 60 sectors.

This is a theoretical exercise and was carried out at the Indira Gandhi Institute of Development Research in Bombay. However, before I go into the details, I present in Figure 1 a general picture of global carbon dioxide emissions. The share of developed countries in total world emissions was 70% in 1988 and as cumulated emissions over the period 1950-88, it was 7%. Average disparity ratio, defined as the ratio of per capita emissions in developed and developing countries, is 7.8. In the case of CO_2 emissions from coal, it is 6 or more. In the case of oil, it is 8.5 and of gas, it is 18.46. Now, gas flaring by the developing countries looks very large but gas flaring accounts for only 1% of the total global CO_2 emissions and developing countries have a very large share of that 1%. Total emissions by each

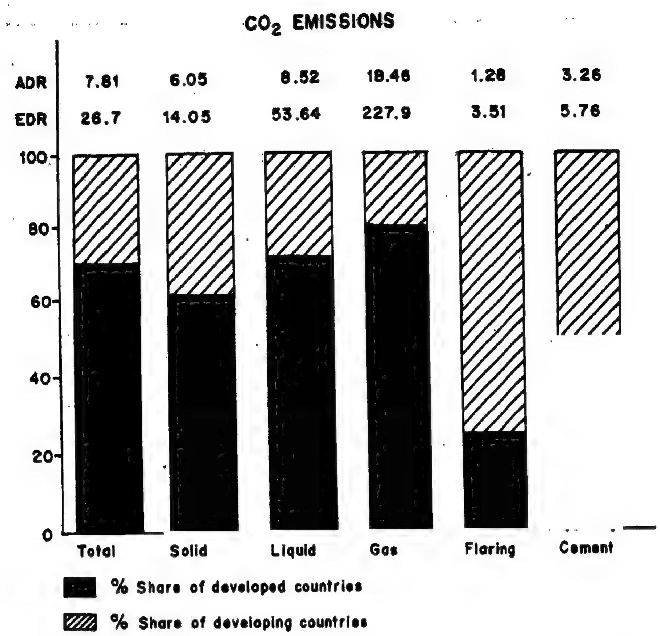

Figure 1. Global CO_2 emissions by sources and regions.

fuel are given in Table 1. Cement manufacture also has a small share in the total emissions. There too, the share of developing countries is only about half.

While the greenhouse effect has attracted much attention from the media internationally, India's environmental priorities are somewhat different. First of all, as shown in Figure 2, environmental concerns divert some of the resources away from development. For example, if a 1000-MW power plant has to be environmentally sound, its capacity is reduced to 850 MW because you have to invest in cleaning up the emissions. So even between environment and development, there is a trade-off.

Within environment, there are two kinds of trade-offs: local pollutants, which is what India is mainly concerned with, and the global pollutants, which have caused concern even in developed countries, only recently. India does not have the responsibility to do anything about global pollutants but we may end up doing

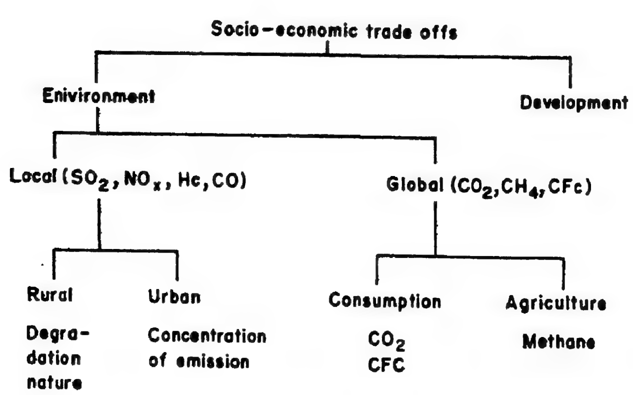

Figure 2. Socio-economic trade-offs.

Table 1. Patterns of energy consumption and CO_2 emissions.

Item	World total (million tonnes of oil equivalent)	Share (%) Developed countries	Share (%) Developing countries	Consumption per capita (kilograms of oil equivalent) Developed countries	Consumption per capita (kilograms of oil equivalent) Developing countries	ADR[a]	EDR[b] USA/
Fuel and electricity							
Solid	2309	66	34	1278	199	6	14
Liquid	2745	75	25	1720	175	10	61
Gas	1611	85	15	1147	61	19	227
Electricity	343	81	19	230	17	13	46
Total	7009	75	25	4376	453	10	35
Diesel	756	72	28	452	55	8	29
Petrol	725	82	18	495	34	15	390
Electricity(thermal)	7040[c]	78	22	4574	397	12	39
Electricity (Total)	11017	79	21	7260	599	12	40
	(Million tonnes of carbon)			Tonnes of carbon			
Global emissions	5723	70	30	3.36	0.43	8	27
Total emissions	112060	77	23				
Cummulative total emissions(1950-1988)							
Solid	2413	64	36	1.31	0.22	6	14
Liquid	2205	70	30	1.33	0.16	8	54
Gas	907	82	18	0.62	0.03	21	228
Flaring	48	25	75	0.01	0.01	1	4
Cement	148.8	49	51	0.06	0.02	3	6

Source: Energy Statistics Year Book (1988), UN FAO Book of Production (1989), Oak Ridge National Laboratory Tape.

[a] EDR is defined as the ratio of per capita consumption of USA and India.
[b] ADR is defined as the ratio of average per capita consumption in developed and developing countries.
[c] Billion kilowatt hours.

Note
1. All total consumption
2. Per capita data were arrived at by calculations.
3. Emission data relate to 1988.

something either as world citizens or due to pressures from the aid agencies. Local pollutants again divide into rural and urban. Global pollutants of major concern are CO_2, CFCs (chlorofluorocarbons) and methane. Here, there is a trade-off between

the consumption of energy intensive items that emit CO_2 versus agricultural activities that are basic to life but involve emissions of methane from paddy fields and livestock.

Within this larger framework, I will now describe some work that we have done relating to India. We calculated emissions from 60 sectors using an input-output table for India. This is a 60 x 60 matrix that states how much of each commodity and service is required to produce various other commodities and services. The *j*th element of the *i*th row of this matrix, a_{ij}, describes the amount of commodity *i* needed to produce commodity *j*. For example, one row of the matrix tells us how much coal used for steel, how much for cement and so on. Similarly, one can find out how much oil and gas are used for the different sectors. We can use this input-output table because the CO_2 emissions depend entirely on how much fossil fuel is used and not on the technology used. Therefore, as long as you know how much fuel is used, you can calculate the emissions with reasonable accuracy (excluding emissions from unburnt coal). Emissions from electricity are accounted for in coal so that it is not counted twice. Thus, whenever fossil fuels are used or cement produced, there are carbon emissions associated with them.

From this, we have calculated the carbon emissions by sectors by using carbon coefficients for each fuel. In Figure 3, estimated emissions for the first ten sectors are shown. Electricity accounts for 28 mt (million tonnes) of carbon; iron and steel, 8 mt; transport, 6 mt; and so on. In developed countries, power and transport

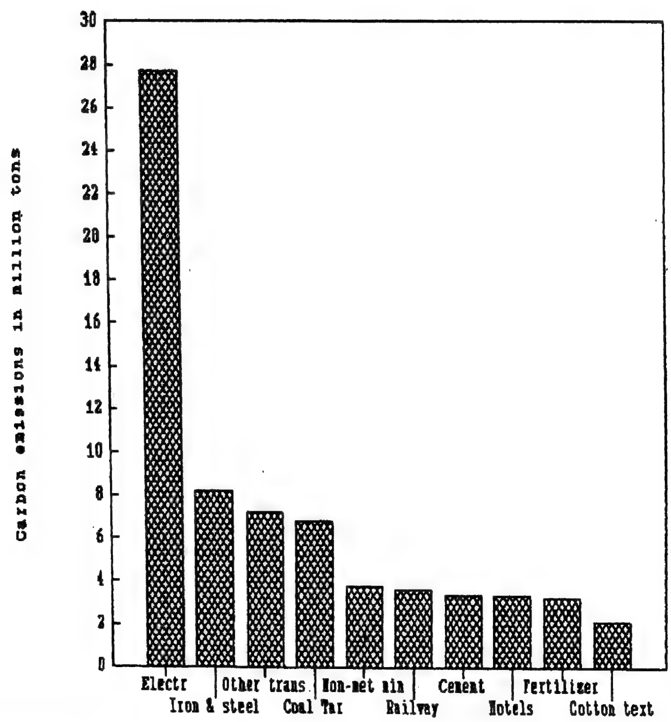

Figure 3. Direct carbon emissions by sectors.

have roughly similar shares. India is a country with four cars and even fewer buses and lorries per thousand people. We are nowhere near the figure of 550 cars per thousand people so emissions from transport are less. Secondly, the electricity sector in India is rather inefficient. Moreover, a considerable amount of electricity is generated by coal, which has the highest CO_2 emissions per GJ of primary energy.

Figure 3 shows that fertilizers, cement, and hotels and restaurants (including tea and sweetmeat stalls etc.) produce about 4 mt of carbon dioxide each.

Figure 4 shows that electricity supplied to households alone (and not that which goes into the making of other goods) ranks fifth and not first. Construction produces the most because all the energy-intensive materials such as iron and steel, other metals, cement, glass, bricks, etc. are a part of construction activity and a developing

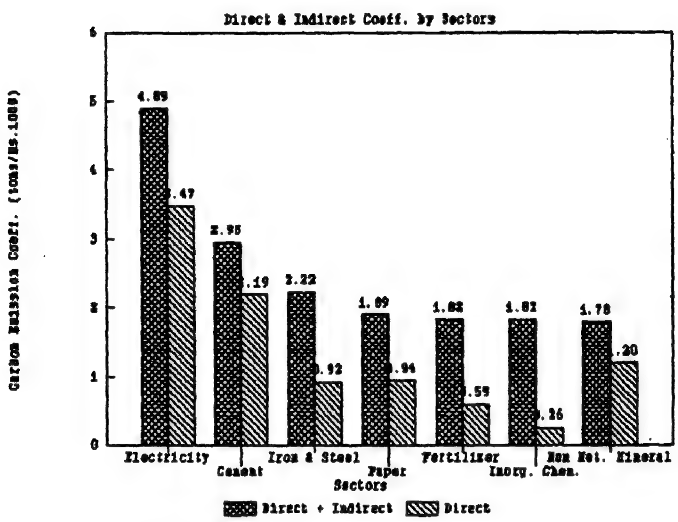

Figure 4. Carbon emission coefficients.

country like India needs to build power plants, roads, houses, factories, and so on as fast as possible. Thus, it is in construction that most of the energy-intensive materials are being used. In Figure 5, the cross-hatched portion represents investment. Food crops do not emit as much carbon because, first of all, Indian agriculture is not as energy intensive as that in developed countries. Moreover, most of the food processing is done at home using labour intensive methods; if added to the share of food crops, the total would be quite high.

Construction by itself—viewed as a service that puts different materials together—does not consume that much energy but when you consider the inputs required to produce those materials, it becomes the largest consumer. That is, the first and second order terms are larger than the zero order terms.

So far, measures recommended for reducing greenhouse gas emissions are mainly directed at improving energy efficiencies because if consumption of fossil fuels is reduced, emissions of greenhouse gases will be lower. However, as can be

inferred from Figure 5, we could reduce GHG (greenhouse gases) emissions also by improving construction efficiency. If you have better construction methods that use less energy-intensive materials, they are as good a measure as improving energy efficiencies. We hope that the global environment facility administrators at the World Bank will note these kinds of results.

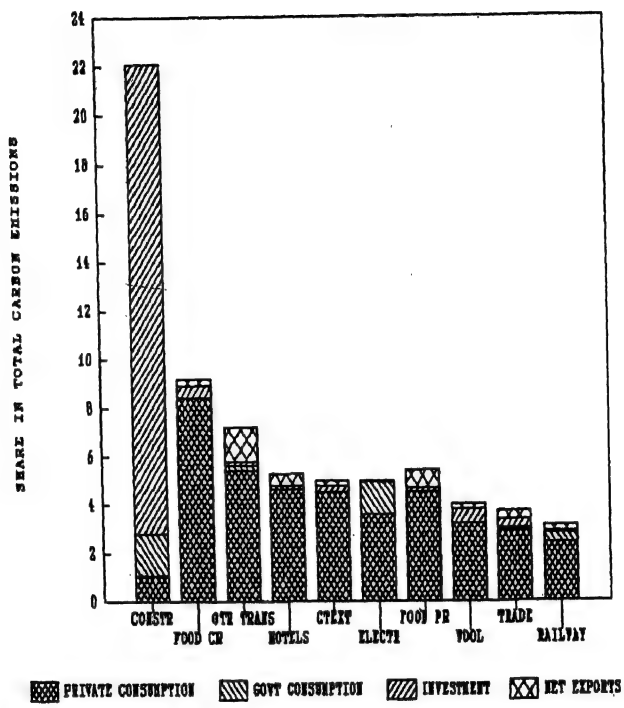

Figure 5. Carbon shares from final demand.

Now, let us discuss some energy policy options for India. Coal has the highest greenhouse gas emission per gigajoule of primary energy. But India has 180 billion tonnes of coal reserves as against perhaps 1.5 billion tonnes of oil. Therefore, a better policy for us would be to save oil and not coal. I present two scenarios in Table 2. Both save roughly the same amount of energy: one saves it by reducing oil consumption; the other by reducing coal consumption. India would like to save oil because oil is imported and it saves us foreign exchange. Moreover, oil costs 3000 rupees a tonne whereas coal costs only 300 rupees a tonne. What you see here are two scenarios that satisfy the same quantum of final demands as the base case does. In the two scenarios we assume that conservation measures will reduce the requirement for coal or oil in each production activity. The costs of such measures are not included in the calculations. However, we can compare the cost and CO_2 implications of comparable reductions per gigajoule of energy input. The difference between the two scenarios shows that CO_2 emissions will be reduced by four million

Table 2. Comparison of Base Case with energy savings from coal and oil.

	Base case	Coal reduction by 10%		Oil reduction by 13.5%	
		Values	Difference with Base Case	Values	Difference with Base Case
Tonnage (million tonnes)					
Coal	121.3	109.17	12	121.3	0
HSD/LDO	14.13	14.13	0	12.22	2
FO/LSHS	5.6	5.6	0	4.84	1
Emissions (million tonnes)					
Coal	66.2	59.58	7	66.2	0
HSD/LDO	12.43	12.43	0	10.75	2
FO/LSHS	4.43	4.43	0	3.83	1
Total	83.06	76.44	7	80.78	3
Value (million Rs)					
Coal	24260	21834	2,426	24260	0
HSD/LDO	41431	41431	0	35838	5593
FO/LSHS	15120	15120	0	13003	2117
Total	80811	78735	2,076	73101	7710
Energy (million GJ)*					
Coal	2183	1965	218	1965	218
HSD/LDO	546.00	546.00	0	473.00	73.00
FO/LSHS	212.80	212.80	0	184.07	28.73
Total	2943.00	2724.78	218.22	2740.55	202.45

* PJ = 10^6 GJ

tonnes when the conservation effort is directed at coal. However, the savings from reduced oil consumption amount to 73 billion rupees whereas those from coal amount to 79 billion rupees—an additional saving of 6 billion. However, this does not include the cost of conservation measures. If the international community would like us to save coal rather than oil in order to reduce CO_2 emissions, funds on this scale are needed.

Since electricity accounts for the maximum greenhouse gas emissions from India, we have looked at it in great detail.

INGRID 2 is a 190-power-plants model developed by IGIDR (Indira Gandhi Institute of Development Research) that considers integrated grid operations. Instead of every SEB (state electricity board) operating in isolation, even to the extent of operating inefficient plants despite the neighbouring SEB having more efficient plants (including the National Thermal Power Corporation), the model recommends some compensatory mechanisms for transferring electricity between states. Thus, wastage of coal could be reduced, which would in turn lower local and global pollution.

In this linear programming model, we introduced a CO_2 reduction constraint. As shown in Table 3, total operating costs for the electricity sector in 1989-90 were 75.8 billion rupees. Following integrated regional grid operation practices (e.g., the

Table 3. Carbon emission reduction in thermal power generation. (Annual run 1989-90)

			Integrated Optimal Operation		
Parameter	Unit	Actual	No conservation	5% reduction	10% reduction
Total operating cost	Million rupees	75816	64092	64893	68464
Total carbon emission	Thousand tonnes	43869	41240	41124	39482
Emission factor	Kg of carbon/MWh	210	196	195	188
Coal consumption	Thousand tonnes	111673	101003	100250	91232
Gas generation (% of total generation)		3.7	1.8	3.9	8.0

Note: Per cent reduction refers to reduction from actual values.

least efficient plants are turned off first as and when there is no demand at night or at certain off-peak hours), the cost could be lowered to 64.1 billion rupees for the same electricity demand. If a 5% CO_2 reduction constraint is added the costs increase marginally, to 64.9 billion rupees, which is still less than the actual cost incurred in 1989-90 without integrated grids. Carbon emissions reduce from 43.8 mt to 41.1 mt a year. India can thus offer to trade reduction in CO_2 emissions with other countries; so long as they invest in India, they can then claim the credit for CO_2 emissions saved. Developed countries invest in Indian power systems and earn credits for CO_2; we get a more modern power system. If you use the inefficient plants a little less, you could reduce some local pollutants as well. Therefore, India has something to gain even locally.

Of course, we are talking about a very highly power constrained system at the moment and the shortages will remain with us. But you will be surprised to know that there are many instances when these power plants are not needed, particularly at night. For example, in the Maharashtra State Electricity Board, peak demands are 6000 MW and off-peak demands are 4000 MW: the problem is this 2000 MW drop in demand. Sometimes, during the night, frequencies go down up to 51; in such cases, it is better to off-load the thermal power plants from the grid. Thus, with some investments in our transmission systems and the computer and communication

systems connecting the power-plant operators, it may be possible to save fuel and lower the global and local emissions.

Coming back to the greenhouse gases and climate negotiation aspects, India should have a fair share in the global commons. Given a fair allocation, a system of tradable emission quotas would provide an efficient and a just way to reduce GHG emissions. The system works as follows. If the world average of emissions per capita is 1.1 t, for India it is 0.2 t, and for the US it is 5 t, then the US has to buy the emission quotas from other countries such as India that emit less than their quota. This is the system which has been discussed by Michael Grubb of Britain, and others at the UNCTAD (United Nations Conference on Trade and Development). At times, reducing emissions in developed countries may be more expensive than reducing them in developing countries. A system of tradable emission quotas is economically efficient, socially just, and environmentally safe.

For example, Mrs Bruntland mentioned in Germany recently that Norway is essentially a hydroelectricity generating country. They cannot reduce their emissions from power plants and their North Sea emissions are for the world, not for Norway alone. Therefore, Norway would like to meet its obligations by investing in developing countries. It is for this reason that we should know, though we are not the major emitters of greenhouse gases, where we are producing CO_2 and how we can reduce it, so that other people can decide if they would like to invest in India. Also if we want to take part in global greenhouse reduction strategies, we should know where to start.

Some people questions the advantage for a developing country such as India to analyse emissions of CO_2 in different sectors—I hope I have given some answers. Essentially, there are three reasons: first, we should understand how much CO_2 we emit and how it is apportioned amongst the sectors; secondly, when we go to the international negotiating table, we should know what are the options available to us; thirdly, some reorientation of our energy and agriculture policy may take place due to global forces. For example, our coal resources are going to lose their value in future; following the greenhouse gas debate, coal is no longer considered as valuable a resource as before. There will be pressure to use more gas in place of coal. There will not be as much international help for coal development and it is quite possible, eventually, that we will have to develop coal resources on our own. So these are the energy policy issues connected with the greenhouse gas debate. When we participate with full knowledge, we can participate constructively in this debate and attain certain objectives that benefit not only India but the whole world.

Note: This work was carried out for the UNCED secretariat (United Nations Conference on Environment and Development).

PANEL DISCUSSION

Session 2b
Impacts (energy demand and supply)

Dr H S Rao

I think we have been looking at a dynamic futuristic situation with a static frame of mind. What struck me most in Jim Skea's paper was the methane aspect. Total contribution to emissions from methane is much less than that from coal or oil because it gives you two volumes of H_2O for every volume of carbon dioxide. But the amount of energy which methane gives (90 btu per cubic foot) is very much more than what you get out of a lb of coal - 13 500 btu when you convert it into the equivalent. So our focus should really be on gaseous fuel and on conversion of a solid fuel into a gaseous fuel if the index is emission of carbon dioxide and the greenhouse effect as a cost factor. I did a modelling study based on work that was done by Henry Linden in the Institute of Gas Technology in Chicago on the Indian situation, and I found that the real pay-off is hydrogasification of coal, i.e. converting coal into methane. Although initially you are putting in some energy, if you allow for the transportation of methane and the higher output that you get from a unit of methane in terms of energy value and lower emissions in terms of carbon dioxide. per energy unit delivered, you find that, overall, you come out as the gainer. Therefore, hydrogasification of coal to methane coupled with long distance transportation might become a priority area relative to the priorities being discussed in this meeting. Similarly, we should emphasize invention and the contributions that inventions make to the changing scenario. For example, emissions from a diesel locomotive per tonne-mile of freight are about one-fourth of those from a steam engine. So the transition from the steam engine to the diesel electric locomotive, which was invented by General Motors at a time when the greenhouse effect was hardly even talked about, has turned out to be a very important invention in today's context. There are many more such inventions waiting to be exploited if only we re-assign our costs taking into account the greenhouse effect or carbon dioxide emissions.

Friction modifiers also provide an area where you can reduce the energy consumption in the transport sector. One of the speakers has paper pointed out how the transport sector is bound to consume a large chunk of the energy. Friction modifiers and drag reducers can cut down on the energy consumption in the transport sector. There are innovative ways of structuring our own industry so that we consume a lot less energy and emit a lot less carbon dioxide. If all the caustic soda industry is be shifted to the North-East, where we have 8 million cubic metres of gas per day, bearing in mind that the conversion of gas to power is a lot more efficient than through the thermal coal based system, and transport the caustic soda to peninsular India, we could save about 500 megawatts of thermal power.

Dr Skea

I would underline your point about methane being a much cleaner fuel. It really is a central element of the UK strategy over the next ten to fifteen years. However, I am a little surprised at the idea that you can start with coal, go through a set of chemical processes, and end up with less carbon dioxide going into the atmosphere for a given unit of final energy demand. I have seen some science fiction style ideas coming out of the Brookhaven Laboratory in the United States, which is involved with hydrogenation—converting coal and then disposing some of the carbon in solid form. Once you look at all the figures, this actually did put less carbon dioxide into the atmosphere. However, the capital requirements for such processes are so large that I am a little sceptical about it. Is there is a coal-burning technology—an integrated gasification combined cycle—in the 45% cross-efficiency range required to bring the efficiency of conversion from coal roughly into the same kind of order of magnitude as gas?

Dr Parikh

I agree with Dr Rao's general observation about the role of innovation but all the coal-related technologies are of greater interest to us considering that we have about 186 billion tonnes of coal and 1.5 billion tonnes of oil. In our Institute [Indira Gandhi Institute of Development Research] we have also conducted another study which suggests that instead of flaring the gas, we could compress it, and use the compressed natural gas as a transportation fuel. Gas is a far less greenhouse-gas-emitting-fuel than petrol or diesel. So there are some technologies around but our mainstay would be coal.

Dr Pachauri

I ended my presentation by saying that R&D has to be a very important element, or even the driving force, to bring about a transition. So innovation has not been overlooked. As to the velocity of capital movement, I do not know what is implied in that. How is capital going to move? Yes, you do need higher returns and shorter

gestation periods. Essentially, it means ensuring viability and efficiency in the use of capital. But we are talking about such a staggering problem—I can give you numbers—that on the basis of even predictable technologies, to bring about a transition, these interventions can at best only meet part of the overall challenge.

Dr J D Sharma (School of Environmental Sciences, Jawaharlal Nehru University)
What is the scope for solar energy in this country, and how do we exploit it?

Dr Skea
I am far less familiar with India's problems but I would have thought that the efficiency and the cost of solar cells is coming down a great deal. Many studies are beginning to show that it is a technology beginning to look possible for India. In Britain, the climate obviously is quite different. Opportunities for renewable energy tend to be of a rather different kind. The two major opportunities that we have are probably wind energy—the government is encouraging that at the moment with some provisions under the Electricity Act—and also perhaps tidal energy. However, there are potential environmental objections to the building of large tidal barrages, perhaps of the kind that are coming up with respect to large-scale dams in India.

Dr Parikh
What I basically was aiming at was shifting from a carbon-based energy scenario to a silicon-based scenario. It could be nuclear or solar, but it definitely means moving away from the carbon cycle.

Dr Anima Bose (Centre for Peace Education)
My question is directed towards Dr Pachauri. I was impressed very much by the data that he supplied. Dr Pachauri, you have suggested a change of lifestyle for sustainable development in India. We have already seen that the household and transportation sectors have been using energy and probably will use more energy. Would you recommend an emphasis on renewable energies instead of total energy as other countries do? I think it should be gradual instead of a tremendous and sudden change.

Dr Pachauri
First, some clarification. When I was talking about lifestyle changes, I was talking about them in a global context. Apparently, it is the countries that are consuming a lot of energy and imposing a major burden on the global environment who should think in terms of lifestyle changes. By that I mean even the spatial pattern of urban development. In North America, apart from the population density being very low, there are suburban areas where people generally live and urban areas where (at least

till 30 or 40 years ago) people primarily worked. This was the result of cheap oil and the efforts of a man called Henry Ford, who invented the automobile. So the entire spatial distribution of population, its work habits, and its recreational habits were built around the automobile. Now that is not going to change overnight but it must change, because that is one segment of the American or the North American way of life which is certainly not sustainable. There is a growing realization even in that country that this must happen. I agree that these changes will not come about suddenly; I cannot see any politician saying that this kind of change must come about in a short period of time and getting re-elected. Basically, it is a question of getting people to realize that what they are doing is not sustainable and somehow ensuring that they see their interests as being identified with the interests of the global society. That is a very difficult job. As far as India is concerned, yes, there are lots of things that we could do. For instance, take this very convention hall; the lighting over here should really be based on compact fluorescence. The architecture that we have in these buildings is certainly not making the best use of energy in a natural way. When you talk about renewable energy, I would go even further saying that in a city like Delhi, there is no reason for us to use electric water heaters at all because solar water heating is entirely viable. (For a couple of rainy days or a stretch of rainy days, you could provide an electrical backup as several countries have been doing). But, if I may submit, this is not happening because—I am afraid this may seem a very simplistic observation—we have over-centralized the whole development of renewable energy and we have over-licensed and over-controlled the development of industry that might give us the products and the devices which would make use of renewable energy possible. We need to get away from that and develop an infrastructure whereby these products are produced properly and are maintained and backed up by an effective after-sales service.

Initially perhaps there was some need for subsidies and for certifying designs but that need became irrelevant five years ago. We should now allow industry to operate on its own. We also need some legislative back-up. For instance, if someone wants to set up a wind farm to feed power into the grid, then there must be a legislative back-up by which a regular return on the investments is assured. Then the industry will take off on its own.

Mr S Shriram

From the industry standpoint I can say that most of the time when it becomes economical for industries to do something, they go ahead and do it—either then or when the legislation is actually enforced or socially made important.

Ms A Rani (Rajasthan University)

Will global warming not lead to lower energy demands?

Dr Skea

I was involved in a study in the United Kingdom of the impacts of global warming in the UK, and in fact that was one of the conclusions we reached for a country that was in the UK's geographical position. If you took the IPCC's (Intergovernmental Panel on Climate Change) central forecast of temperature rise, we concluded that the degree days for heating in the UK would actually fall by about 25% by the middle of the next century. The danger is that it is less easy to see in what part of the world demand for air-conditioning might actually rise as temperatures go up. In parts of Southern Europe, the demand for air-conditioning at home might go up: inefficient room air-conditioners and also the possibility of a greater number of motor vehicles being air-conditioned and reducing efficiency. So it is a mixture of good and bad news on the energy demand side.

Mr Manas Ray, Power Engineer

This relates to the 27% reduction in oil in the second scenario assumed by Dr Parikh. Why do we consider CO_2 emissions per capita and why not per unit of GNP, or per square kilometre of land area of the country?

Dr Parikh

The two scenarios that I presented—10% reduction from coal and 27% reduction from oil—both save the same amount of energy (2 million gigajoules). Because we are using more coal, a 10% reduction saves the same amount of energy as that from a 27% reduction in oil. That is why I compared two separate scenarios; though both save the same amount of energy, one is more relevant to India's perspective and the other for the global perspective. I wanted to demonstrate that saving an additional 2 million tonnes of CO_2 costs about 15 billion rupees. The second question was about CO_2 per GNP, which will perpetuate the same kind of world order that we see now; CO_2 per GNP in developed countries is going down but the GNP is so high—as much as 13000 dollars—that their CO_2 budgets will be very high whereas we wish to see a more sustainable world wherein people have comparable incomes; not very similar but at least enough to have a decent living. And if you want to have that vision of the world then you need CO_2 per capita. CO_2 per square kilometre is also a valid point but from a different point of view. My objection to that is it would mean that Saudi Arabia should have more CO_2, or may be Canada. These countries are large and will end up having more CO_2 but they are so sparsely populated. Canada has 14 million people, and Saudi Arabia has 10 million people. So we are not really bringing the world together. One could think of a mix of two indicators also. Let me point out the problem with CO_2 per capita: it should not encourage population growth. We have recommended in our UNCED (United Nations Conference on Environment and Development) paper a base population,

e.g. that in 1980 or 1985, and then preparing the per capita budget from that population so that more populous countries are given appropriate concessions in their carbon budget.

S K Gupta (Indian Oil Corporation Ltd)
There is a long debate going on all over the world regarding the use and installation of nuclear versus thermal power stations. Different countries have their own choices. I wish to know from the Panel the present status as far as India is concerned in this regard. The second question is for Dr Skea, about the use of lead-free petrol. In the USA and Canada, more and more lead-free petrol is being sold due to environmental problems. In India we are yet to make a start in this direction. In our refinery, we add lead to increase the octane number. This is really very harmful and is restricted due to environmental reasons. What is the status in the UK in this direction?

Dr Deo
India has a fairly ambitious nuclear energy programme and the target till recently was 10000 megawatts by the turn of the century, though it has been scaled down now. If those plans are achieved, we would probably have about 10000 megawatts by 2004-2005. But there are a number of imponderables, the most important being the availability of capital or finance. The programme is now being handled by the Nuclear Power Corporation, which gives them a little more flexibility for raising finance, but I am not too sure whether they will be able to meet the demands of capital within the time-frame required. The second point about the nuclear power programme is its viability. Unless we can bring down the gestation period (I am not going into the other aspects, which are highly subjective), the viability of nuclear power as it is today is highly doubtful.

Dr Skea
By 1993, all new cars sold in the UK must be fitted with catalytic converters, so obviously it is necessary to have lead-free fuel available for these vehicles. The cars on the road now are of three kinds: vehicles that can run only on leaded-petrol; vehicles that can run on both leaded and unleaded petrol; and the new catalytic converter cars that of course need lead-free petrol. A year or two ago there was a fairly strong campaign to boost the amount of lead-free petrol that was sold in the UK. This was done really by two basic measures: a publicity campaign followed by tax measures that made lead-free petrol much cheaper than leaded petrol. As a result of that, something like 98 or 99% of all petrol stations now sell lead-free petrol in the UK and the proportion of petrol that is lead-free is, as I recall, something between 35 and 40%, and will increase as catalytic converter cars come into greater use.

Dr Sukumar Devotta (National Chemical Laboratory)
I just wanted to know from the Panel whether there is any cost factor attributed to CO_2 reduction. Similar to that in energy conservation where we give credit to steam saved at, say, Rs 300 per tonne. Is there any cost factor attributed to CO_2 reduction per kg of CO_2 reduced? If so, what is it?

Dr Pachauri
I will be very happy to send you some information on this. We have a grouping of eleven institutions, called the Asian Energy Institute, and we have been tackling precisely this problem, trying to estimate the emissions of greenhouse gases and the costs of mitigation strategies. We have estimated the cost fact, at least as a first approximation, for a number of countries and we have come up with fairly interesting answers.

Dr Parikh
Internationally, this has been estimated. The estimates range from \$80 a tonne to \$200 a tonne. But it all depends on what measures you are thinking of and how much CO_2 you want to reduce. There are even measures with negative cost because the benefits are so high. For example, if you use energy more efficiently, you not only reduce CO_2 emissions but save fuel; thus it is a negative cost solution. For India, our estimates range from \$40 to \$120 per tonne.

Dr Skea
There is a great deal of work being done in this in the developed world, mainly through the idea of conservation supply curves, looking at the various measures that are possible. And there are others who say that some of these measures have a negative cost, in the sense that they lead to some benefit regardless of the carbon dioxide emission aspect. The critical question is the rate of return on capital that is set for the measures: it could be 5 to 10% of the rate of return that a utility might look for while investing in power plants. At such a rate, indeed you can identify measures with a negative cost. But particular sectors and even householders tend to expect much higher rates of return on capital: 20 to 50% are the implied rates of return that people have in mind. Bridging this gap between the ideal and the actual rates of return in different sectors is one of the key policy questions. We also have to remember the costs associated with many conservation measures. There may be hidden costs such as the cost of acquiring information, the transaction costs of actually carrying it out and so on. When the conservation supply costs are developed, I am not sure that they are always put together. It is something certainly to keep in mind.

Dr John Vallamattam (Editor, *Indian Currents*)
It was mentioned that population is high in certain areas and low in other areas. In this connection, I wanted to ask if the environmentalists, besides proposing that

there should be collaboration on the international level—the developed nations helping the underdeveloped nations to reduce their output of carbon and so on —are also considering a proposal to shift population in terms of permitting migration to the thinly populated countries of the world. Because if you speak of a world community then we should think of not only sharing the resources that we have but also sharing ourselves.

Dr Deo

There are some utopian solutions. When we talk of solutions we have to consider the international environment and whether they would be acceptable. What you describe would be a very easy solution but it is debatable whether it will be acceptable to the world which is divided into the North and the South.

Dr Prodipto Ghosh (Tata Energy Research Institute)

I have one brief comment and one question for Dr Deo. The comment relates to the previous discussion about abatement costs for carbon dioxide. It is very well known in the literature that there is a dichotomy between two different approaches. The first is what is called the bottom-up approach in which one looks at specific techniques for CO_2 abatement and very often, when aggregated over an economy, one may get a negative series of abatement costs. The second is the top-down approach in which one looks at the cost of abatement starting from macro-economic models, in which we assume that all factors in the economy are optimal choices.

My question relates to the models that make various projections and the implicit expectation that policy makers would take these seriously and build policies around these projections. But a policy maker might question the projection and turn them down. So could Dr Deo comment on why these modelling results should be taken seriously.

Dr Deo

When we talk of energy policy in India, we are basically following the Plan model based on five-year plans. The energy policy objectives are given in the energy plan. But do we really attain them? The working group on energy policy in 1979 had recommended that our emphasis should shift from oil to coal but exactly the opposite has happened. So when it comes to the policy, the one advantage offered by these models is a long-term view. My idea in presenting the models was to explain the demand scenario—whether we will really be able to meet those demands. My personal opinion is that we will not be able to meet this demand at all. There is no point in speculating that in 2004 or 2005 the oil demand would be 130 million tonnes—it is just not possible to meet it. Similarly, there are problems with electricity for which today we have no answers unless we really restructure the energy industry,

and that involves many issues. So I leave this question open. Policy makers can be sensitized; models are very useful that way because somebody can point out that policy makers have taken a very short-term view particularly so in a democracy where politicians think of only five years period. In fact they think of even shorter periods if you do not have stable governments. The models are a good reminder that energy policy must have a 15- to 20-years perspective.

Member of the Audience

Incentives to power plants are based on the PLF (plant load factor) which is a measure of how much energy is produced and not of how efficiently it is produced. But CO_2 emissions can be reduced by efficiency improvements too. Has the Energy Management Centre given any thought to such incentives?

Dr Deo

You made a very valid point. The efficiency of Indian power industry is very low; and with the present installed capacity, we can meet future demands only to a limited extent. But we should not forget that demand is growing rapidly and we must augment our generation capacity. We are also to work out a scheme where PLF would not be the only indicator. The idea is to offer monetary incentives to the employees of the power stations.

Member of the Audience

Most of the increases in energy consumption or carbon dioxide emissions come about because of the large numbers of people in developing countries and their ever increasing populations. Have we all given up the idea that we can actually reduce or slow down the growth of population in our countries, or that is not a scenario which is at all being considered?

Mr Shriram

I hope we have not given up that idea. It is frightening to perceive what could happen if we do not reduce our population and this also relates to the comment earlier about sharing populations. To a large extent, it will happen. The number of illegal immigrants in several countries is no longer a matter of just a few tens or twenties. We are living on one single planet, and whatever happens in one part of the world has a growing impact over a period of time in other parts of the world. Population stabilization is a very important goal that we have not addressed as seriously as we should have.

Dr Sujoy Basu (Jadavpur University)

A question on British energy policy: burning gas may be a short-term policy, but how long is gas going to last? Perhaps Britain might have to go back to coal. The

US has an intensive programme on clean coal technologies. Is there any emphasis on this in the UK?

Dr Skea

It is quite revealing that energy and carbon dioxide forecasts for the UK often go only as far as about 2005 or 2010. If the calculations are extended further, the future begins to look more frightening in terms of emissions. Most of the gas that is going to be used for power generation in the near future is coming from the UK sector of the North Sea. Now that is sustainable for a certain period of time but beyond that, if Britain is going to continue to use more gas, we shall need to import gas from further afield. There are two particular sources: one is the Norwegian sector of the North Sea—some deals are beginning to be made there—and the other area (in the longer term) is Siberia. But, everybody in Europe is looking to Siberian gas —Western Europe, Eastern Europe, and Russia itself. So the availability is an open question. The cost of bringing gas from further afield will inevitably rise because gas costs are often very much related to how far you actually have to bring it. Eventually, a situation might be reached where coal could once again begin to look more attractive. Now we can all do our different scenarios but the scenario wherein coal begins to look attractive again might be reached around—I do not know— 2005 to 2020 or thereabouts. The UK is interested in the idea of clean coal technologies, and British Coal at the moment is working on a concept called the topping cycle which could perhaps raise the efficiency of conversion of coal into power generation to the upper 40s in terms of a percentage, which would be substantially better than the present average of lower 30s in the electricity industry. But looking into the long-term future involves other questions as well, e.g. what happens to the nuclear power programme in the UK? Can renewables be developed? How far can electricity efficiency be increased? There is a whole range of competing technologies one should look into for long-term forecasts.

Mr D P Aggarwal (Physical Research Laboratory, Ahmedabad)

We have been working in the field of paleo-climates so we see how changes took place in the past and do not take a panicky view of the modern era while looking at a long time-range. About 125000 years ago and even earlier, up to 300 ppm levels had been reached, and nature took care of them. I am not subscribing to the Gaya Principle or something like that but since most of the new science and developments come from the West, sometimes what happens in the tropical countries is ignored. For example, we have vast deposits of calcium carbonate in the form of concurred calcite etc. This is a sink into which carbon dioxide is going at a particular period. At some time they were perhaps sources. Every time calcium carbonate forms, it becomes immobile and part of carbon dioxide goes into it. Maybe you reach a point

when the climate becomes so cool that it starts emitting it back. We have not given enough emphasis to look at this sort of data and also some simulation experiments in the laboratory itself, where you increase the plants, and the plants provide a lot of calcium, and that takes away the dissolved carbon dioxide. The only thing is that now it is being pumped too fast. Whether we have mechanisms in nature itself which could take care of it? I am not saying we should become complacent but we should understand nature and emphasize some experiments, projects that look at these aspects. They are very cheap experiments. Not enough attention is being paid to such crucial points, which will improve our understanding of natural systems.

Dr Parikh
We have to realize that we are adding an additional trend—a really substantial trend —which nature will have to take care of. It is not a random event, going from 9 terawatts to 24 or thereabouts. Whether it is a rate nature can take care of we are not sure. Till then, we should think about our own ways; it will be our good luck if nature absorbs all this but we should not count on it.

Mr Chadha (Department of Ocean Development)
Whenever we talk of pollution-free technologies and renewable energy, we talk only of wind energy and solar energy. We never look at a very important source of energy which can be developed and which can be a source of a large amount of energy in India, namely energy from biomass. It may appear that energy from biomass is also polluting because it will lead to CO_2 generation, but that will happen only if you cut trees. If you generate trees in a cycle and use them and continue this cycle, carbon dioxide generation will also be absorbed by the trees that are planted. This is a good technology which will also use lots of recently deforested land; it will save India from flood; it will give employment to the poor; and it has many other benefits.

Dr Parikh
Afforestation projects are being considered as a partial solution to the CO_2 problem. However, one should realize that the maximum amount of CO_2 sequestering takes place when the plant is in its growing stages. Once it reaches a sustainable state, it ceases to be of any help is absorbing CO_2 because by then it is in equilibrium with nature and it is no different from the existing forests. So this is a short-term solution. We could certainly use it to meet our energy needs but then whenever you burn biomass, CO_2 is released. So there are no free lunches here in this system.

Dr Skea
Britain is one of the most systematically deforested areas in the world if you compare it with what it was 600 to 700 years ago. Some afforestation is going on and there

has been some interest in short-rotation forestry being used as a source of biomass energy in the UK. The problem is that the country is relatively densely populated, with other demands on agricultural land; all kinds of calculations indicate that biomass would make a very small contribution in a country like the UK.

Dr Deo

Whether biomass would be a net absorber of carbon dioxide is difficult to say. It will depend upon various factors, e.g. how it is used. But in the context of developing countries like India— when we studied the rural energy problems—the main demand 90%) is for cooking or household energy. With deforestation and the difficulties that the rural people have to face, what was once a non-commercial fuel is also today becoming commercial for the small towns. So with respect to the kind of model you are suggesting, we have to utilize biomass. There is no other solution to the rural energy problem. Most of the times we have been talking about only commercial energy but when it comes to non-commercial energy, although the various models show that the share of non-commercial energy will decline, the fact remains that 70% of the population is in the rural areas and will be dependent upon this traditional fuel. For them biomass will be the most important source.

Member of the Audience

I would like to add to what the panellists have had to say in reply to the question by Mr Chadha. It is true that biomass if harvested sustainably is generally considered to be neutral in terms of carbon emissions. However, most biomass-burning devices, typically traditional fuel stoves, generate very significant amounts of what are called products of incomplete combustion: hydrocarbons, carbon monoxide, and so on. And these products of incomplete combustion are very significant greenhouse gases themselves. While it is true that sustainably harvested biomass may be neutral in terms of carbon, it is also true that it is probably a significant net emitter of gases which contribute to radiatory forcing.

Mr Chadha (Department of Ocean Development)

I talked about biomass gasification and not biomass burning.

Mr Shriram

One could possibly add alcohol-related fuels as well.

Dr Deo

This aspect needs to be studied. In gasification too there are problems of efficiency etc. Whether biomass will be a net producer or it will sequester carbon is difficult to say.

A review of international response strategies

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Mr Chairman and distinguished Colleagues

In the last two days we have heard a great many experts in various fields. In saying a few words about the progress of the international response to climate change, I should confess that my expertise lies only in the arcane art of removing brackets and adding commas. In other words, I come before you as a negotiator and not as an expert.

I began to consider what I should say during the last meeting of the INC (Intergovernmental Negotiating Committee) in Geneva just before Christmas. At the end of a long and hard negotiating meeting, it is sometimes tempting to agree with the view of the NGO (non-governmental organization) newsletter *ECO*. In one edition, they offered a way of speeding up interventions. Delegates would simply have to say which of three options they supported. For example, whether you thought that action on CO_2 should be (a) immediate, (b) left to the market to determine, or (c) a subject not raised in polite company.

It also offered the delegates a choice of what the convention should contain: (a) appropriate commitments to limit global warming, (b) nothing in particular, or (c) John Sununu's holiday plans.

I hope it is clear from what I have said that the UK is a supporter of the first option. In truth of course the progress we have made towards an international agreement on climate change is in many ways remarkable. Climate change is truly a global issue. All countries will suffer from its impacts, though some more rapidly than others.

However small, all countries contribute in some way to the problem; and the responses that may be available to individual countries will cover every sector of the economy and concern every individual.

This universality of interest made it essential that the international effort to reach agreement should be on as wide a basis as possible. Discussion on a possible global

agreement was prompted in part by the work of the IPCC (Intergovernmental Panel on Climate Change) in the preparation of its first report. A legal instruments group, which the UK was privileged to chair with Canada and Malta, compiled a list of possible elements for inclusion in a framework convention on climate change. This type of instrument, following very much the example set by international action to protect the ozone layer, was recognized by a great many countries as a first step in a global response to climate change.

In the light of the IPCC's work, at the Second World Climate Conference in November 1990, ministers and representatives from 137 countries called for negotiation on a convention to begin as soon as possible.

Political leaders recognized that, despite the uncertainties, the risks of climate change justified the world taking sensible steps now to limit those risks.

To arrive at a universal and transparent process to prepare a convention, it was essential that we seek a proper mandate for the negotiations. Only the United Nations can provide such a mandate and in its resolution in December 1990, the General Assembly established the INC (Intergovernmental Negotiating Committee) and set out guidelines for its work.

It asked the INC to prepare an effective convention containing appropriate commitments in time for it to be signed during the UNCED (United Nations Conference on Environment and Development) in Brazil in June 1992. The General Assembly also indicated some of the key issues which the convention should consider.

It asked the secretariat to the committee to ensure close co-operation with the IPCC as the primary source of best available scientific advice on climate change.

It made arrangements for financial support to promote the participation of developing countries in the negotiations.

It asked the United Nations Environment Programme and the World Meteorological Organization to be the primary supporters of the secretariat and invited them and other UN bodies to contribute to the INC's work.

And in its preamble the resolution recognized certain key aspects of climate change such as the possible effects of sea level rise on islands and coastal areas; the fact that most current emissions originate in developed countries; and that these countries must take the lead in combating climate change.

Against the background of this demanding schedule, the INC has now held its first four sessions. We began in February 1991 in Washington with a two-week session which, to be frank, did little more than clear the procedural ground for the committee's work. This was essential preparation but not rapid progress.

We met again in June in Geneva and the two working groups the committee had decided to establish met to begin their tasks. One was to look at commitments different parties would make under the convention, and the other at the mechanisms

and institutions for implementing and monitoring these commitments. The debate began in earnest on all the issues in the convention.

We resumed our roving meetings in Nairobi in September and perhaps not only thanks to the weekend the delegates spent in the game park, all delegations contributed to substantive progress in defining the views of countries on the main areas of concern. At the end of the session we were in a position to invite the chairs of the working groups to prepare the first real text for the convention.

This was the basis of our work in December, again in Geneva. From that meeting just a few weeks ago we came home with this single negotiating text for the convention. True, it contains several hundred pairs of brackets, indicating where agreement remains to be reached; true, we are still some way from agreement on some key issues. But it is also true that the commitment shown by more then 100 national delegations demonstrates the continued expectation that we will meet the remit the UN has given us, to complete the convention before June this year.

Inevitably perhaps, most attention in the international debate has tended to focus on areas where our understanding is best—on CO_2 emissions and the energy and forest sectors. Discussions have also sought to put into practical effect the catchphrase of the negotiations, that countries share a common but differentiated responsibility. Professor Menon described the different challenges in the energy sector. For the UK and other developed countries, we need to consider ways of adapting the existing structure of our energy sector; what sensible use of non-CO_2 sources of energy we can make in the future; greater efficiency in our use of energy; and products, processes, and planning to maintain growth without increasing CO_2 emissions from present levels.

For developing countries, the issues are different. For India there are higher priorities in terms of meeting the basic needs of its people. As development proceeds towards this goal, energy demand will rise but to help tackle climate change, as we heard yesterday, this can be met in ways that limit the increase in CO_2 emissions. At the commonwealth heads of government meeting in Harare last autumn, the British Prime Minister John Major suggested that one objective developing countries might consider in their national responses would be to keep the rate of growth in their CO_2 emissions below the rate of economic growth. This is an area which Dr Pachauri discussed yesterday. The challenge might well be seen in terms of avoiding the mistakes developed countries made in the past in our inefficient use of fossil fuels before the climate change problem was recognized. Improving the efficiency of production, transmission, and use of energy can help every country contribute to the global response to climate change.

As we heard yesterday, in many countries wood is an essential fuel. Yet deforestation removes a sink or reservoir of carbon and burning the forests increases CO_2 emissions. Fuelwood itself of course is not necessarily a net contributor to

CO_2 emissions. All countries can work towards a more sustainable use and management of world's forests. It is one way in which we can help to maintain a proper balance in the use of natural resources. In the UK we are looking at ways in which we can sensibly increase our forest areas again, after many years of decline.

So where do we stand? And what sort of convention can we expect to achieve by June? Let me suggest a few thoughts based on the expectations and hopes of the UK government.

It must be a convention that is based on certain fundamental ideas. That is the means by which we shall reach an agreement which will gain the support of as many countries as possible.

First, it must be an equitable convention. It must have a proper balance of commitments. Developed countries should take a lead by giving a specific commitment to stabilize their CO_2 emissions. We hope this commitment will be to stabilize emissions in general at 1990 levels by the end of this decade.

In the UK, we put out a first set of measures we were taking in the major White Paper on the environment in autumn 1990. It described a whole series of steps from a legal requirement on the electricity industry to use a certain amount of renewable energy, a major publicity campaign to encourage energy efficiency in the home, a best practice scheme to help industry become energy efficient, and measures to improve the efficiency of vehicles and reduce fuel consumption. Jim Skea stressed the importance of built environment and we have created a major new grants programme to improve energy efficiency. Other developed countries are adopting similar programmes. We are also examining with our European Community partners the details of possible tax on carbon/energy.

We should also be clear that the convention should contain an agreed mechanism by which developed countries will provide financial and technical resources to assist developing countries meet their commitments under the convention.

We hope that the GEF (Global Environment Facility) pilot project launched by the World Bank, UNEP, and UNDP will evolve, with amended arrangements for governance, to become the comprehensive umbrella mechanism for channelling these funds to developing countries.

Second, it must be universal. During the INC negotiations so far, a central element that has emerged is the idea of national plans or strategies. All parties would undertake to prepare a national plan appropriate to their own national circumstances and development. These would describe the measures each party is taking to limit emissions of greenhouse gases and to protect and enhance sinks, notably forests.

For developing countries, these plans would also provide the context in which they can identify the projects and measures they are proposing to take for which financial and technical assistance is sought. I should stress that nothing which might be expected of developing countries under the convention should be seen as

inhibiting continued development. Rather, in pursuit of sustainable development all countries including the UK and India could be expected to pursue measures that support development while also helping to project the environment.

The third principle is transparency. All citizens have an interest in the actions being taken by their country and by others. The negotiations have also been considering establishing a body under the convention which would have several key functions in this area:

- to assist parties in devising their national plans;
- to receive reports on what parties have been doing and provide any advice that is requested;
- to monitor the measures parties take to promote compliance with the convention;
- to share with all parties helpful information and experiences in implementing different measures; and
- to report to the conference of parties and so to the world at large on all the actions taken to fulfil the objectives of the convention.

Fourthly, the machinery of the convention in all its forms must be democratic, reflecting properly the range of countries who are parties to the convention.

Finally, the convention in all its articles must be based on co-operation. In scientific research, financial support, technology transfer; in all its aspects it will be a success only if we are able to work together.

This then is the sort of convention we hope for—structure that is balanced and sets a basis for us to go forward. Whatever we achieve in June will only be a start. As the science progresses and our understanding increases, we will need a flexible structure to respond to changing circumstances and needs. Only individual countries will be able to judge how they can best contribute to the international response, but our framework and machinery must support them in their efforts and ensure that we adopt a genuinely co-operative approach in which we can learn from each other's experiences.

What role are the UK and India playing in the negotiations? For the UK an important part of our participation is through the joint positions taken by the European Community at the INC. The Community has consistently led the call for specific commitments to be agreed by the developed countries. And the other member states have supported the UK's approach to the basis and machinery for the convention I have described.

The UK is also well placed historically to try and bridge the differences between Europe and the USA. The US, the world's largest CO_2 emitter, remains a key to the convention as the only major industrialized country not to have set itself a CO_2 target. Prime Minister John Major and my own Secretary of State have emphasized

the importance they attach to the US's full participation in the convention. We will continue to seek that participation.

India is playing if anything an even more significant role in the negotiations. Their delegation is led by Additional Secretary Mr Dasgupta, a vice-chairman of the committee and a most influential figure in its debates. India is a most important contributor. As a large and growing country, it has much to contribute—as we have heard—in terms of scientific and technical expertise. Professor Menon described the long tradition of the India Meteorological Department and others have pointed to the contribution of Indian experts in work on methane emissions. The search for effective and economic responses to climate change will call for the pooling of such expertise world-wide and the sorts of solutions developed in India may be of benefit to the rest of the world, both developing and developed countries.

As the negotiations reach their climax, I am sure that India will be one of the central players in achieving the final agreement. We hope the UK can play its part too.

Thus, this seminar takes place at a crucial time and involves participants from two countries at the heart of the convention negotiations. It has, I am sure, been a unique opportunity for all of us to learn more of the concerns and perceptions of our two countries.

Basic approach of developing countries to the negotiations for a climate change convention

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I have been asked to make a very brief presentation on the basic approach that India has taken in the INC (Intergovernmental Negotiating Committee) negotiations. It is not just the position of India; it has been co-ordinated with other developing countries.

In front of this specialized audience, I need not dwell at length on the definitions that form a part of my presentation. I can very conveniently skip all the definitions of the various phenomena that we are addressing ourselves to in the negotiations.

I shall begin with our assessment of the scientific evidence available regarding the greenhouse effect. Scientific evidence indicates that human activity has caused a considerable increase in the emissions of greenhouse gases. However, significant uncertainties remain in predicting the extent of the likely rise in temperature. Uncertainties also apply to the role of oceans as primary sinks in absorbing carbon dioxide, the behaviour of clouds, and the effective contribution of forests as carbon dioxide sinks. Furthermore, while cholorofluorocarbon emissions and carbon dioxide emissions from fossil fuel burning have been estimated with a reasonable degree of confidence, this is not the case with other greenhouse gases such as methane, nitrous oxide, and water vapour. The uncertainty over the regional impact of global warming is even greater, with a high degree of uncertainty being associated, for example, with forecasts for southern Asia. However, while the precise scope of global warming remains unclear and considerable uncertainties remain as I outlined earlier, it is broadly accepted from available evidence that earlier options of precautionary measures may be necessary. At present, efforts are under way for phasing out ozone-depleting substances, several of which also contribute to global warming. In line with the precautionary principle, steps also need to be taken to limit and reduce the emission of carbon dioxide since it is the major contributor to the greenhouse effect. Burning of fossil fuels in the developed world is by far the most important source of carbon dioxide emissions. It is argued by some that

since every country emits carbon dioxide, all must bear responsibility for taking corrective action. However, global warming is not a consequence of the emission of greenhouse gases per se, but of excessive levels of such emissions. Normal limits and levels are in fact extremely important for maintaining climatic stability. Responsibility for global warming accordingly rests with those countries responsible for excessive levels of per capita emissions. Cumulative carbon dioxide emissions in the post-industrial revolution period have contributed to the present problem and this factor would also need to be considered. Since responsibility for contributing to global warming lies with those countries with excessively high per capita levels of emissions of carbon dioxide, it follows that it is the responsibility of those countries to undertake early corrective action. Furthermore, the primary responsibility for climate stabilization devolves upon the developed countries not only because of their disproportionate past and present contributions to the global warming phenomenon but also because of their disproportionately greater financial, technological, and other capabilities. Any agreement on limiting carbon dioxide emissions would also have to take into account the entirely legitimate aspirations of developing countries to develop. I am glad that Mr Hammond emphasized this point.

This is, however, not to say that the developing countries should remain silent spectators in the international response process. While they can have no legal responsibility, at least in the near future, for taking corrective measures, they may, in accordance with their national development plans, programmes, and objectives, consider feasible measures for which the full incremental costs involved are met by the provisions of new and additional financial resources by the developed countries.

It must also be recognized that the process of development will inevitably lead to increasing greenhouse gas emissions by the developing countries and there can be no justification either in environmental or economic terms for retarding growth in the developing countries. A just and equitable solution would thus lie in significant reductions in levels of per capita emissions by developed countries so that over a period of years these converge with rising per capita emissions in the developing countries. The developing countries in turn would have to accept obligations once their own per capita emissions reach an agreed common ceiling or range. It is also important to realize that the reduction in per capita emission levels can be achieved by the developed countries without sacrificing their high living standards, partly through technology upgradation and partly through promoting sustainable lifestyles. There are examples which demonstrate that for the countries which possess the requisite capital resources, environmentally sound technology can be made compatible with high per capita productivity.

In conclusion, I would like to state that in India we are fully sensitive to the importance of not pursuing a path of industrialization that leads to environmental

perdition. We are also fully supportive of international co-operation in the field of environment. However, there are legitimate concerns of developing countries, some of which I have just outlined, that must be taken into account in any global endeavour. We look forward to the emergence of a global partnership that seeks to protect the environment while addressing the specific developmental needs of the developing countries.

The international policy response to climate change[1]

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The political significance of climate change in 1992

There can be little doubt that some of the more dramatic forecasts about global warming and sea level rise spurred many countries to commit themselves to aggressive greenhouse gas reduction policies. Table 1 shows the commitments that individual countries have made so far.

There can also be little doubt that some of the impetus to securing an international *quantitatively based* greenhouse gas agreement has declined. The reasons for this are as follows:

1. *Changing science.* Some of the science is changing and the results so far suggest that the upper range forecasts of the IPCC (Intergovernmental Panel on Climate Change) may be too high. Improved understanding of GCM (General Circulation Models) appears to suggest a 'business-as-usual' rate of warming of 0.2 °C rather than some 0.3 °C because of the greater than expected capacity of oceans to absorb heat. Additionally, the net effect of CFCs (chlorofluorocarbons) is being questioned. As they deplete the ozone layer, more low frequency heat from the earth is escaping than would otherwise be the case—a cooling rather than a heating effect. It is not so much the *science* that matters here as the *perception of science.* Given the uncertainties in global climate modelling, the outcome of more refined information and better interpretation could reveal faster rather than slower warming. The fact that the refinements have so far led to lower forecasts of warming will be seized upon by politicians and, no doubt, some scientists.[2]

2. *Economic recession* or, as some writers would have it, economic depression in the Western world. There is evidence that concern for the environment is correlated with income (Figure 1). We should not therefore be surprised if there is some political cooling about global warming.

3. *Premature commitments.* Some suspicion that politicians committed themselves to action without first exploring the implications of action. The most important point

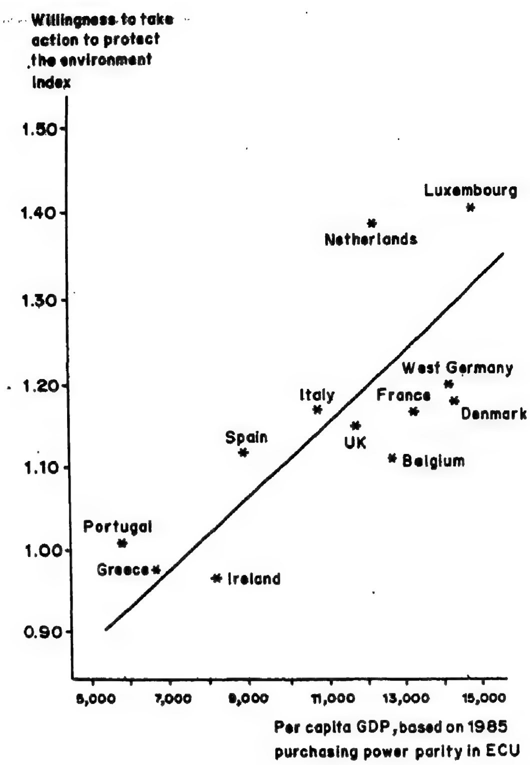

Figure 1. Average willingness to take action to protect the environment as a function of per capita GDP (gross domestic product), by country.

in this respect is the discovery that, in countries other than the few where there is a very rapid turnover of capital stock, the only way to secure greenhouse gas reductions on a significant scale is through increases in the price of fossil fuels. Such increases are no more popular in rich countries than in poor ones. 1992 happens also to be an election year in at least the UK and the USA.

4. *Doubts about economic damage and concerns about costs.* Some doubts have been raised about the economic damage that would be done by global warming, combined with some concerns over the cost of controlling it. Especially influential has been the study by Nordhaus.[3] Figure 2 illustrates the main findings of this study. The

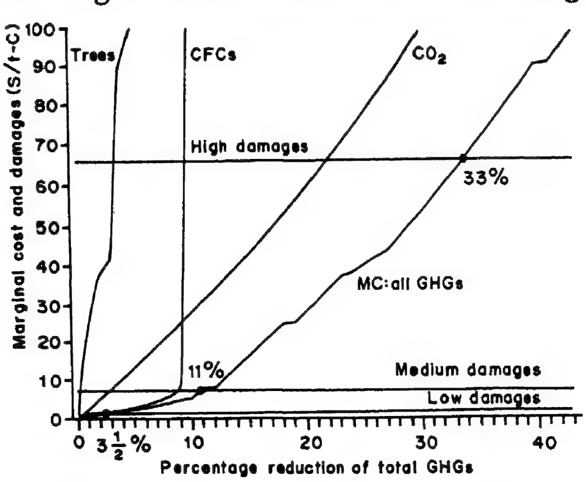

Figure 2. Nordhaus: cost-benefit.

'optimal' reduction in greenhouse gases is given where the extra cost of reducing them is just equal to the extra damage avoided. To make reductions would be to incur costs greater than benefits (i.e. reductions in avoided damages). The damages correspond to 0.25%, 1%, and 2% of world economic product. Even at 2% damage, Nordhaus's required reductions are small. 33% reduction may appear big but it is a reduction in the level of GHG (greenhouse gases) emissions that would otherwise have occurred around 2050. Moreover, it is a reduction in the composite of greenhouse gases (expressed in CO_2 equivalents). The diagram shows that it is most cost-effective to remove CFCs first. The residual action needed to reduce CO_2 turns out to be very small. For the 'medium damage' case (1% of world GNP) the reduction is only 2% of CO_2 off trend. For high damage (each tonne of CO_2 as C does \$66 damage), CO_2 is reduced by around 20% off trend. Nordhaus makes it clear that he does not regard this higher figure as credible. Nordhaus is therefore speaking of carbon taxes in the range of \$60-70 per tC to achieve very modest reductions in CO_2. Carbon tax studies generally focus on taxes of around \$100 per tC (tonne of carbon) to be sure of achieving the year 2000 targets (Table 1).[4] This is equivalent to approximately \$13 a barrel of oil. By comparison, the two major price hikes of the 1970s were each around \$20 a barrel in 1990 prices (Figure 3). Once again, the issue is not so much what is true—there are many reasons for disputing the Nordhaus analysis—but how the economic arguments are being perceived.

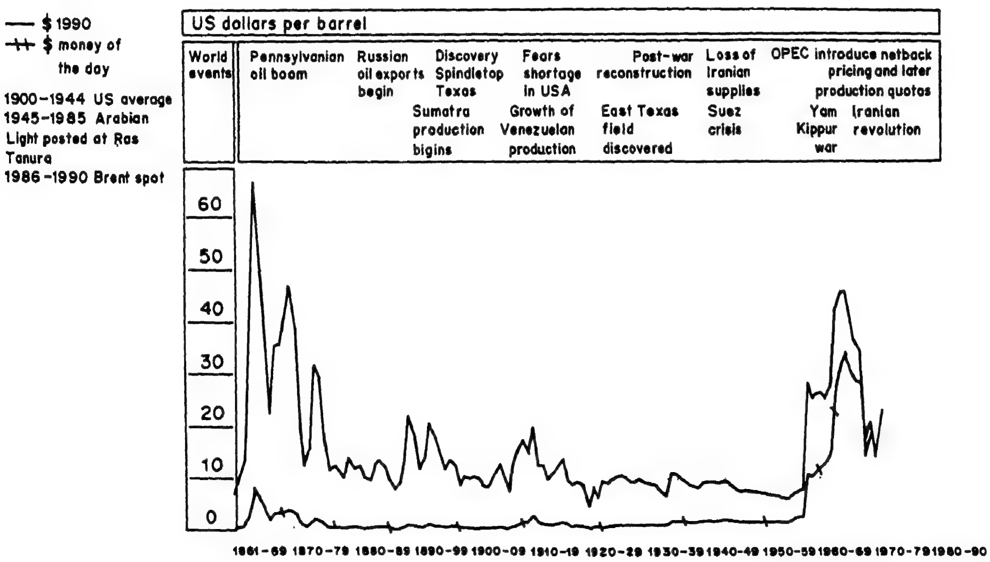

Figure 3. Fluctuations in price of oil as a consequence of world events.

Why global warming still matters

There are several reasons why the pursuit of firm GHG emission-reducing policies ought not to be dampened.

Table 1. Status of commitments of OECD (Organization for Economic Co-operation and Development) countries on global climate change.

Country	Type of commitment	Gases included	Action	Base year	Commitment year	Conditions/Comments
Australia	Target	NMP, GHG	Stabilization 20% reduction	1988 1988	2000 2005	Interim planning target; to be implemented if others take like action.
Austria[a]	Target	CO_2	20% reduction	1988	2005	Still needs parliamentary approval.
Belgium[b]	EC agreement	CO_2	(see endnote[c])			–
Canada	Target	CO_2 and other GHG	Stabilization	1988	2000	–
Denmark[b]	Target	CO_2	20% reduction	1988	2005	Implementation plan adopted.
Finland[a]	Target	CO_2	Stabilization	1990	2000	–
France[b]	Target	CO_2	Stabilization	1990	2000	This is a per capita per year target of less than 2 tons of carbon
Germany[b]	Target	CO_2	25% reduction	1987	2005	Larger % reductions in eastern Lander
Greece[b]	EC agreement	CO_2	(see endnote[c])			–
Iceland[a]	EFTA agreement	CO_2	(see text)			–
Italy[b]	Target	CO_2	Stabilization 20% reduction	1988 1988	2000 2005	Non-binding resolution.
Japan	Target	CO_2	Stabilization	1990	2000	On per capita basis; implemented if others act likewise.
Luxembourg[b]	EC agreement	CO_2	(see endnote[c])			–
Netherlands[b]	Target	CO_2	Stabilization 3-5% reduction	1989/90 1989/90	1995 2000	Unilateral action committed.
	Target	All GHG	20-25% reduction	1989/90	2000	Unilateral action committed.

Table 1. contd

Country	Type of commitment	Gases included	Action	Base year	Commitment year	Conditions/Comments
New Zealand	Target	CO_2	20% reduction	1990	2000	–
Norway[a]	Target	CO_2	Stabilization	1989	2000	Preliminary.
Portugal[b]	EC agreement	CO_2	(see endnote)			–
Spain[b]	EC agreement	CO_2	(see endnote)			–
Sweden[a]	Target	CO_2	Stabilization			Conditional on *like* action and only applies to sectors not subject to international competition.
Switzerland[a]	Target	CO_2	At least stabilization	1990	2000	Interim target.
Turkey	–	–	–	–	–	–
U.K.[b]	Target	CO_2	Stabilization	1990	2005	Conditional on like action. A 20% reduction in GWP of UK emissions of all GHG in 2005 compared with 1990 levels.
United States	Commitment to set of policies	All GHG	Stabilization	1990	2000	Stabilization achieved in part by CFC phase out.

Note: EC agreement means that country falls under EC-wide target but has not yet developed its own target.
[a]EFTA member.
[b]EC member.
NMP = Non-Montreal protocol (refers to greenhouse gases other than those covered under the 1987 "Montreal Protocol on Substances that Deplete the Ozone Layer" and its subsequent Amendments i.e. greenhouse gases other than CFCs, HCFC, halons, carbon tetrachloride, and methyl chloroform).
GHG = Greenhouse gases.
GWP = Global warming potential.
Source: IEA Secretariat.

1. Uncertainty works both ways. If the world does little or nothing about GHGs and the scientists then tell us that there are significant impacts, we will have lost valuable time in a context where warming itself may be irreversible. This is the *insurance argument*. To overcome fears that the purchase of insurance will be expensive it is necessary to focus on the so-called 'no regrets' policies, i.e. those where the benefits *to the controlling nation* exceed the costs to that nation. Whilst this argument typically put in terms of low, zero, or even negative cost conservation activities which simply reduce energy costs and import bills, it needs to be broadened to account for those cases where the *incidental* benefits from reducing greenhouse gases, especially from reducing CO_2, make it worthwhile for an individual nation to undertake that policy. For a developing nation, for example, much energy conservation will be self-financing because of reductions in energy-costs of production. But reduced energy consumption will also reduce conventional pollutants such as SOx, NOx, particulates, and ozone. These 'traditional' air pollutants tend often to be ignored in the developing country context, yet there is growing evidence that their impacts on human health are significant. As yet, we have little idea of the quantitative importance of these incidental benefits from policies aimed ostensibly at CO_2 reduction in developing country contexts. One study of Norway suggests they could be very large. Table 2 shows the results of a domestic cost-benefit study of reducing CO_2 in Norway through a carbon tax. Some back-of-the-envelope calculations suggest that the gains may be as high as $800 per tonne C.[5]

2. From the point of view of the South, CO_2 reduction policies will also make major savings on energy bills and hence in import expenditure[6]. In 1990, the developing world consumed some 730 million tonnes of oil and refined products. The growth rate of consumption was 3.1% per annum in the 1980s.[7] Hence by 2000 consumption will be in the region of 995 million tonnes of oil. If the growth rate was cut to 2.0% per annum, *without affecting economic growth rates*, then 100 million tonnes of oil would be 'saved'. At $20 a barrel ($150 per tonne) this is a saving of $15 billion annually, *or the equivalent of a third of the entire flow of official aid to the developing world*. Aggressive CO_2 control policies would surely reduce oil consumption rates further. A reduction to 1% growth per annum would save 185 million tonnes of oil or $28 billion; and zero growth would save $39 billion, not far short of the entire aid budget.

3. Clearly, if the pure energy bill savings (paragraph 2 above) plus the incidental social cost savings (paragraph 1 above) are to be achieved, the North has to transfer technology and funds to the South in addition to current flows of funds. This will be the essence of the debate at Rio. The mechanism for raising the funds is, however, problematic. Whatever the rights and wrongs of the existing configuration of global pollution, the reality is that the transfers on the scale needed will not come about through threats, appeals to conscience, morality, or international justice. That is not

Table 2. The costs and benefits of controlling carbon dioxide in Norway.

Scenario: Norway 'freezes' CO_2 emission at the level reached in 2000. A rising fuel tax is used to achieve the freeze. As an illustration, the price of fuel oil would be raised by 50% in 2005 and 100% in 2010.

Costs	Billion N.Kroner (1986 prices) in 2010
Costs measured in terms of forgone GNP	27.0
Domestic benefits	
Reduced forest/lake damage due to acid rain	0.1
Health improvements from reduced NOx, SO_2 CO and particulates	7.6
Reduced corrosion	0.2
Traffic accidents	2.7
Traffic congestion	2.9
Road damage	3.6
Noise	2.1
Total domestic benefits	19.2
Net domestic benefits	-7.8
Net domestic benefits as % GNP in 2010	-0.8

Source: S Glomsrod et al., 'Stabilization of emissions of CO_2: a computable general equilibrium assessment', Central Bureau of Statistics, Oslo, April 1990.

an ethical statement. It is a pragmatic one. There is a chance, however, that the North will make the transfers if in so doing it feels that it stands to benefit too at one and the same time. If the South confers benefits on the North, the North may see the transfers as payments for the benefits. This is not so much the 'polluter pays' principle, as the 'beneficiary pays' principle. One vehicle for such transfers is a carbon tax imposed world-wide but re-distributed according to some allocational rule. The allocational rule is the subject of debate, of course. It is naive to think that the North will agree to a rule whereby re-distribution takes place on a per capita basis, and just as naive to think that the South will agree to a rule based on GDP (Gross Domestic Product). A rule based on 50% GDP and 50% population would make Africa, Latin America, and Asia (especially) net gainers. At $10 per tonne carbon, they would receive around $12 billion per annum.[8] Every $1 tC tax would raise $5.3 billion. Better rules than the 50/50 GDP/population rule can be devised. Indeed, Barrett has shown that all the rules proposed so far in the literature will fail because they always make at least one major emitter worse off under the co-operative outcome than under the outcome where no cooperation takes place (Table 3).[9] Indeed, the 50/50 rule considered above fails because the (old) USSR nations lose significantly. Barrett analyses a 'Kantian rule' in which each country chooses an abatement level at least as large as the uniform level it would like all countries to undertake. Crudely

Table 3. Some proposed allocation rules.

	Rule	Rationale
1.	Negotiate a global limit CO_2 emissions and allocate this limit on the basis of CO_2 emissions per capita.	"The moral principle is simple, namely that every human being has an equal right to use the atmospheric resource. The economic principle follows directly: those who exceed their entitlement should pay for doing so. The practical effect is obvious: it would require the industrialized world, with high per capita energy consumption, to assist the developing world with efficient technology and technical services." Grubb (1989, p.37). See also Pearce (1990), Bertram et al. (1989), Hibiki et al. (1989), and Burtraw and Toman (1991).
2.	Negotiate a global limit on CO_2 emissions and allocate limit on basis of CO_2 emissions per unit of GNP	"... carbon emission are tied to economic activity and the objective should be to maximize the efficiency of economic production" (Grubb, 1990, p. 36). Grubb argues that measurement of GNP would pose a problem, although Pearce (1990) maintains that countries do agree on the basis of GNP measures through the UN statistical system. Both Grubb and Pearce argue that this rule would discriminate against poor countries. Grubb (1990, p. 36) refers to the rule as "an untenable proposition".
3.	Uniform percentage reduction in emissions	Minimal disruption to *status quo ante*, and hence involves smaller transfers. Common rule used in other international environmental agreements. Criticized by Grubb (1990, p. 36) on the basis that it would "reward the countries which are currently the most polluting".
4.	Allocate permits to poor countries	"Since the world's rich are the chief polluters of the atmosphere, there are strong equity (and some efficiency) grounds for allocating entitlements initially to the world's poor, so that the necessary purchase of entitlements by the world's polluters would generate a financial flow from rich to poor; hopefully providing resources to encourage development of the poor countries." (Bertram et al., 1989, p. 14).
5.	Allocate permits in inverse proportion to per capita consumption of fossil fuels.	"This would directly reward those countries which moved seriously to renewable energy, while at the same time helping countries with low levels, of development and hence low total energy consumption." (Bertram et al., 1989, p. 15)
6.	Choose an overall level of cost to be borne by all countries and then set each country's emission reduction so that abatement cost relative to pre-control income is the same for all countries.	Based on ability to pay (Burtraw and Toman, 1991)
7.	Choose an overall level of cost to be borne by all countries and allocate this cost such that abatement cost relative to pre-control emissions is the same for all countries.	Based on "polluter pays" principle (Burtraw and Toman, 1991).

Table 3. *contd*

8. Agree on a total quantity of emission entitlements and then have an international agency auction these off to the highest bidders.	TCEEs would be allocated to countries with the highest willingness to pay. However, the resulting allocation is also likely to reflect ability to pay. Although the auction revenues might be used to address this problem, Pearce (1990) concludes: "... it is unlikely that an auction approach to permits would be acceptable."
9. Set total emissions equal to the capacity of the environment to absorb greenhouse gases, allocate these on the basis of population, and set a fixed price on permit trades. Countries that emit in excess of their entitlements should be fined at a rate which exceeds the fixed price on permit trades.	"... sustainable development demands that human beings collectively do not produce more carbon dioxide ... than the earth's environment can absorb ... in a world that aspires to such lofty ideals like global justice, equity and sustainability, this vital global common should be shared equally on a per capita basis." (Agarwal and Narain, 1991, p. 13). "Fines should be ... given over to a 'global protection fund'. The fund can be used to assist these countries which are affected by climate destabilization and to develop technologies that will reduce greenhouse gas emissions. These technologies can then be used by all humankind. Such a system should provide an incentive to countries like India to keep their share of greenhouse gas emissions low and force countries like USA to reduce their emissions rapidly—and, thus, all will join the race to save the planet." (Agarwal and Narain, 1991, p. 20).
10. Allocate TCEEs on the basis of land area.	"... would be easily defined and measured and would offer a disincentive to high population densities. But the absence of any link to human activities makes it impractical ... In short, the combination of a lack of any underlying ethical basis and perverse consequences in practice rule out this criterion." (Grubb and Sebenius, 1991, pp. 16-17).
11. Historical allocations such as a cumulative limit on CO_2 emissions divided equally between industrial and developing countries, or cumulative emissions per capita.	Potential global warming damage is related to atmospheric concentration, which depends in turn on cumulative emissions (taking decay rates into account) rather than current emissions. "Historical responsibility as a principle for allocation possesses considerable intrinsic appeal, but regardless of the index chosen faces immense difficulties." (Grubb and Sebenius, 1991, p. 17).
12. Mixed and transitional allocation systems, such as a weighted average of population and current emissions, employed with a total emission target.	"... has many of the broad features of a per capita system, but ... carries the flexibility for negotiations to affect the scale of transfers implied by the allocation, without compromising the environmental target." (Grubb and Sebenius, 1991, p. 21).
13. Two-tier or multi-tier allocation schemes, where obligations are uniform within a group of countries, but not across different groups. For example, industrialized countries might face obligations based on current emissions, and poor countries might face per capita obligations.	Like Rule 12, this rule seeks to de-polarize negotiations by reducing transfers to a level that is acceptable to the industrialized countries and yet provides incentives for poor countries to participate in the agreement. See Barrett (1991c).

Note. For complete bibliographical details of the references cited in this table, see Barnett S. 1992. Allocation methodologies for CO_2 burden sharing. London Business School (*mimeo.*)

put, whatever one wishes others to do, one must wish to do that oneself. On this basis, each country would choose a uniform abatement level for itself that maximized net *domestic* benefits. Each country's chosen level would differ since each country's costs and benefit functions differ. Putting these different abatement levels together results in a situation where each country is generally better off with the agreement than without it. Yet transfers still take place.

Conclusions

There are some signs that the political impetus to secure a meaningful agreement on greenhouse gases, and on CO_2 in particular, may be waning. It would be a tragedy if it waned to the point where little or nothing happened. The tragedy lies in the possibility that the worst or even reasonably serious climate-induced damage occurs because the world took no action; in the lost chance to reduce the associated damages from CO_2 emissions, i.e. the damage from conventional pollutants, from congestion and from traffic accidents; and from the lost opportunity to set in motion North-South transfers that have as their motivation the self-interest of the North. None of this denies the moral case for such transfers.

Endnotes

1. The views expressed in this paper are those of the author alone and must not be taken as representing any viewpoint of Her Majesty's government.
2. None the less, the possible change in the role of CFCs should work against the position of the USA, which has consistently argued that its achievements in reducing CFCs have reduced any obligation it might have to reduce other greenhouse gas emissions.
3. W Nordhaus, 'To slow or not to slow: the economics of global warming', *Economic Journal*, 101, July 1991, 920-937; W. Nordhaus, 'A sketch of the economics of the greenhouse effect', *American Economic Review, Papers and Proceedings*, 81, No. 2, 1991, 146-150. Especially influential in terms of the view that the costs of control will be very large has been A Manne and R Richels, 'Global CO_2 emission reductions-the impacts of rising energy costs', *Energy Journal*, 12, No. 1, 1991, 87-107. Manne and Richels estimate that a $250 per tC tax would be required to cut world-wide emissions by 20%, equivalent to a five-fold increase in the price of coal.
4. See D W. Pearce, 'The role of carbon taxes in adjusting to global warming', *Economic Journal*, 101, July 1991, 938-948.
5. To work this out, proceed as follows. Norway emits roughly 10 mtC currently and growth in CO_2 emissions is tax about 2.3% per annum. By 2000, when the hypothetical carbon tax is introduced, emissions would be 12.6 mtC. By 2010, the year for which benefits are estimated, emissions would be 15.8 mtC. If emissions are frozen at the 2000 level, avoided emissions are therefore 15.8-12.6 mtC = 3.2 mtC. The benefits of these avoided emissions are 19.2 billion NK, or some $2.7 billion, or about $800 per tC.
6. For this analysis it makes no difference if the oil is imported or produced domestically in the South. Every barrel of oil saved is either a saved import or a barrel that could be exported.
7. All estimates computed from *BP Statistical Review of World Energy*, 1991 edition, London.
8. See A Shah and B Larsen, 'Carbon taxes, the greenhouse effect and developing countries', Unpublished manuscript, World Development Report, World Bank, Washington DC, 1991.
9. S Barrett, 'Allocation methodologies', Unpublished paper, London Business School, London, 1991.

Global and local environments: an arbitrary divide?

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Mr Chairman, let me begin by making a few remarks about myself. I am one of those who believe that one of the best things that we have gained from the British is our system of democracy, which gives me the opportunity to speak my mind. Secondly, I do not come from a culture that is known for the British skill of understatement. Therefore, I am going to be blunt.

If you are looking at the world from the perspective of a woman in the Himalaya, it does not look very pragmatic, but extremely atrocious. There is no element of pragmatism in it. If one has to walk for hours and hours every day just to meet one's basic needs, the whole world will look atrocious; it will not matter whether it was the British who destroyed those forests or whether we have continued to do so after independence.

From that perspective, the subject of global warming would hardly look impressive. My own interest in global warming began one evening while I was having my dinner watching the news on India's television--Doordarshan—which suddenly brought on a news item from Washington, DC, saying very proudly that India was the fifth largest emitter of carbon dioxide and, therefore, contributing to global climate change. The news item also said that the UN supported this study.

But when we started looking at these data closely, we began to see many issues energing. Very soon, I found that fifteen years of my own effort in trying to create an understanding and awareness of environmental issues, and a social legitimacy for those issues, was being questioned. The social legitimacy of environmental issues in India does not arise because people in Europe are talking about them. It arises out of our own social, cultural, and economic context. We were able to create a social legitimacy for environmental concerns in this country by arguing that when the environment degrades, it is the poor who get affected the most. Therefore, any development that does not take care of the environment is bad development. If you go back to the 1970s, you get to see of the environment versus development

debate. This debate was very strong in 1972 at the Stockholm Conference. But we were able to diffuse that debate and get a legitimacy for environmental concerns in this country by arguing that if we are interested in getting rid of poverty and creating employment and sustainable livelihood,—all those wonderful phrases that environmentalists now widely use—you have to have development in a way that is environmentally sound. But suddenly, here was a thesis that was trying to say that it is the poor of the world who are contributing to as big an environmental problem as the destabilization of the world's climate. We had green ministers in this country saying that we should stop eating rice and we should stop keeping cattle, regardless of how important these things might be for the survival of the poor. When we started looking into the data—for reasons of politeness I will not mention the names of the institutions that produced these two reports—we found that these data, which were masquerading in the name of science, were actually intensely political in their interpretation. Science gives you hard facts but when you interpret them to say who is responsible, you enter the arena of politics. The mathematics itself was, therefore, political at its heart. We took the same basic data, however strongly we may have disagreed with it; and we took the same mathematical model but changed one assumption. I presume it is the right of every single human being in the world to make his or her own assumptions. It is not the right of just a few scientists or a few professionals or a few organizations to make their assumptions. When we brought in a very simple assumption that all human beings are equal, the same model and the same data gave us dramatically different results.

Obviously, the interpretation of the global warming data is a political matter. This is not to say that the other party was wrong. The other party was as right as we were because everybody has a right to make their assumptions, whether you live in New Delhi or in Washington, DC. But it is on those assumptions that responsibilities are based, and we were able to prick that scientific bubble,

I want to put in front of you a few points that need to be considered. When we talk about global warming as resource managers, we are talking about the management of a major global resource called the atmosphere. I have been deeply interested in the issues of managing forests. Learning from that area, essentially what we are saying is that we have to move from the management of the atmosphere as a free-access common property resource, as it has been treated until now, to a managed common property resource. The entire refrain of the debate until now is that we have to manage this common property resource called the atmosphere from the point of view of sustainability. We must not destabilize the geochemical and physical processes like the climate that operate up there. But I have not seen any common property resource being managed well unless sustainability is accompanied with the principle of equity. We can discuss and debate how this principle of equity can be built and what it means, but we cannot do anything fair

and useful to all without the principle of equity. The atmosphere does not exclusively belong to any Indian nor to any Briton. It belongs to all of us. It is a common property resource. It has been used as a free-access resource where we can dump as much waste as we want and we can thereby grow our economy in as cheap a manner as possible. This is what has happened over the last 100 years, which is why we are facing a crisis today.

If we carry this argument forward then what it means is that now we have to set a global quota for the pollution of that resource to keep it sustainable. But then that quota ought to be shared equitably. For instance, if we say that instead of, say, 8 billion tonnes of carbon that we put into the air in the form of carbon dioxide today, we have to reduce these emissions to 5 billion tonnes of carbon, the question is who has the right to that 5 billion tonnes of carbon and in what measure? It is my simple presumption that every single human being has an equal right to those carbon emissions. Anybody who exceeds his or her quota has to pay a fine. The North is not talking about being fined: the North is talking about self interest. If the North has put that pollution into the air which today threatens my atmosphere—it is after all as much mine as anybody else's—then the North has to be fined for it. That is what international law and national law until now, for the last thousands of years, have been built upon. In other words, we have to set up a system in which there are tremendous disincentives for those who are polluting, to a point that is damaging, a common resource called the atmosphere. And those who are not polluting must get incentives so that they do not increase their pollution higher. This cannot be done through institutions like the GEF (Global Environmental Facility), i.e. through systems of aid and charity. If we are talking about managing a global resource, then it has to be done as a matter of right of all human beings and we need institutions that generate automatic transfers. Fines do not get paid as charity, they get paid as automatic transfers.

Associated with this argument I want to put before you another dimension which annoys me greatly. I always believed that whenever there is a growing understanding of a global environmental crisis, the world community will join ranks and begin to see the problems of others. And yet in the international political arena of environment, in the last two years I have seen nothing but an effort to divide the world's environmental problems into two sets of issues—global and local. Suddenly the problem of global warming has become global, even though it has tremendous local dimensions. It is produced by the cars of North America and Europe, not by Indians. Whereas problems of the developing world have suddenly become local, with no understanding or appreciation of the global dimensions of those local problems. For example, firewood use and the problems it causes are described by OECD (Organization for Economic Co-operation and Development) as a local problem today. And, as a result, we get an instrument like the GEF that will deal

only with global problems. Global as defined by the North includes bio-diversity even though that is not a global problem. Bio-diversity is the resource of Arunachal Pradesh. GEF also deals with global warming, ozone, and cleaning up of international waters. But what about our problems of land degradation, water degradation—in the Sahara, in the Andes, in the Himalaya—all of which have tremendous international dimensions? I will give you one example of the disparities that exist today. Today, if we want to replace the entire firewood consumption of the developing world, the total amount of energy that is needed is equal to the energy content of the petroleum used in one American city called New York. And, if I am wrong by a few percentage points, throw in the petroleum consumption of Los Angeles and my calculation would be dead right.

Which woman in the developing world would not like to have access to kerosene? Who wants to walk for 8 hours a day to get firewood and then face high levels of smoke burning that firewood? But access to kerosene is determined by the international market. It is not determined by the poor woman in the Himalaya. Access to it is determined by the indebtedness of nations, by the international terms of trade. So local problems also have tremendous international dimensions. So what is global and what is local? Let us not get into this kind of argument which UNCED (United Nations Conference on Environment and Development) has got into and global warming is repeatedly pushing us into, namely global issues are those that we will discuss internationally and for which there will be international funds available through the GEF and other instruments like that, but local problems are problems that developing countries will deal by themselves, with their own resources, while we all turn a blind eye to their international dimensions.

If we have to move towards global environmental management we have to develop a system of environmental rights for all human beings. Use of instruments like conventions, aid, trade, and debt are all levers of power in the hands of the North. Some may call them international instruments, but I call them Northern instruments. They are nothing but levers of power in the hands of the North. But if we are talking about this 'one world' which all of us have to get together and save, I want to ask all of you one simple question. An American NGO (non-governmental organization), the American government, or the British government using their levers of power can today intervene in my country to say what should happen or should not happen from the point of view of environment. But if there is a Bangladeshi in this crowd who feels very, very angry at the fact that the North cannot make up its mind and still talks about uncertainty of global warming, which is probably going to destroy half of his or her country, then what is the lever of power that that Bangladeshi has to influence the North? Nothing! We can write as many articles we want but the *New York Times* will not publish our point of view.

There are no levers of power that we have for enforcing corresponding obligations on the North. Every system that has been developed in the last two years puts obligations on us. Obviously, this is unacceptable. We have to build a world in which there is not just a distribution of responsibilities, but a re-distribution of power to manage this world equitably.

Let us stop playing games. We are saying we must all join together. But why ever so? What have we done to destroy the world's environment? We may have destroyed ours, but we have done very little to destroy the world's environment. But then the Northern argument is: look at the rates of growth of your emissions, 30 to 40 years later you may be destroying the world's environment. Now this is a bit of a sick joke. People who have already destroyed the world's environment, who have created a stock of carbon dioxide which is up there in the atmosphere threatening global warming, are not being held accountable. We have to change our modes of behaviour today for something we might do 40 years later. Those who have already committed murder are preaching to us that we should not commit murder 40 years later. We are already being asked: Do you want to follow our development route? Don't you want to learn from our mistakes? This is something I get to hear in every interview I give to a Northern journalist and every conference I go to. 'Don't you want to learn from the West's mistakes?' I have also been a person who has also been saying that India should learn from the North's mistakes. I am a great fan of Mahatma Gandhi. I have been saying that as well. But hearing it from the West is amazing. Why doesn't the West learn from its own mistakes and set a good lesson for all of us? If you go to the UNCED prepcoms (preparatory committees), everybody is talking about the fact that we need to control our population. But any simple mathematics will tell you that the environmental impact is a product of two things, population and consumption levels. Give me one piece of evidence of what the West has done to control its consumption levels or even to study them. If anyone can find me even five good studies on the problem of consumption in the North, let alone taking action about it, I will be surprised. Yet there are numerous efforts being made to control population. This is not to say that it should not happen. I see that as a women's rights issue. Women cannot be seen as producers of babies after babies, but we do not have to be lectured on this. The North has to look after its own courtyard before it talks about the international responsibilities of the South.

Scientific basis for response of developing countries

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I will talk about those scientific parameters that determine the options for our choice. I also have another point. I have just come back from the meeting of the IPCC (Intergovernmental Panel on Climate Change) Working Group 1 in China, which talked about and finalized the scientific update supplement of the Climate Change Working Group 1, and I would refer to one or two statements made there.

Provided that our choice—whether our response is policy-related or technology-related—is science-based, the first point is that there are continuous changes in perceptions. The perceptions will go on changing with time: what we think today about our scientific imperatives does not remain the same for ever. I will give a few examples.

Some of the changing perceptions about global change can be traced to the fact that there are other actors in the system now. One of the actors is tropospheric ozone, which is globally increasing, and another is the recent change in the reaction of the OH radical with methane, which changes the lifetime of methane. Then there is the new parameter of sulphate aerosols which were until recently considered local because of short lifetime, but are now beginning to be as important as those greenhouse gases which have long lifetimes, e.g. carbon dioxide or the CFCs (chlorofluorocarbons). So we have another actor in the scene.

There are also the comments from scientists from developing countries about how they see their problems. Justly, they feel that most of the developing countries are at the receiving end of the problem. The three countries that are significant producers of greenhouse gases are Brazil, China, and India. But leaving these three out—I will make a statement about these three later—the others put together form a very negligible source. So what we are really concerned with are the effects of global change on these countries that are contributing little, whether it is sea level rise or agricultural changes, etc.

The second concept, again in the scientific context, (and this is also one of the

recommendations of the IPCC Working Group in China) is that the inventory of the greenhouse gases should be made by the countries themselves. It could be on the basis of statistical data that they might get from somewhere else or on the basis of emission factors that they may themselves derive or get from some other sources, but it should be they who should make them and then decide on the priorities. Coming back to the three countries that do contribute in some measure to greenhouse gas emissions—China, Brazil, and India—the problems in these really reduce to the problem of carbon dioxide from fossil fuels in the case of China and to some extent India, and from biomass exploitation in case of Brazil. Another parameter that has been talked about on many occasions is the methane from the rice paddies and animals.

Composition of the atmosphere also changes: all the conclusions that we make are based on the present composition of the atmosphere, with a certain proportion of carbon dioxide or methane or CFCs or nitrous oxide, or of ozone. As these proportions change, many of the conclusions will change.

A major point relates to the estimate of the extent of global change, which will influence our strategies and the policies. A key parameter that has been introduced earlier but has come under a lot of criticism and was also discussed at great length in China, is the GWP (global warming potential). Now how is it defined? It is defined by the forcing function of injection of 1 kg of a greenhouse gas relative to that of carbon dioxide. It is assumed that the entire amount is injected at a time and not spread over a length of time, which is the real situation. This is the definition. There are several problems in this definition and, as I said, there was a good deal of discussion about whether global warming potential, as it is now defined and used and quantified, should be used for policy options. The feeling was that there should be a warning—about the uncertainties, about the inadequacies, about changing proportions of the gases that will occur automatically over time. It should not be used as basis for policy options unless all the boundary conditions or the limitations are known.

Now what are the limitations? One limitation I mentioned is that the emissions are spread over a period of time. The second limitation is that everything is based on the current composition of the atmosphere. As the atmosphere goes on changing, its composition changes. So how do we decide whether the equivalent warming from methane is so much as compared to that from carbon dioxide or from CFCs? How do you decide that? That is going to change. How do we decide what it will be 50 years hence? So the second thing is the time span used for calculations—the time durations used—differ. Should you take 20 years as the time span? 50 years? 100 years? What value do you take? In the meeting in China, we decided on a time span of 100 years. That again can be debated.

The third point is about the indirect effects. You all have heard about them.

The recognition that indirect effects can be very important is a more recent phenomenon and proper quantification is still not possible. The China meeting did not want to quantify the actual value of the indirect effects. For example, in the case of CFCs, the ozone that is depleted in the lower stratosphere has a negative greenhouse effect—it is a cooling effect. So it reduces and perhaps totally cancels the warming effect of CFCs.

Now methane: the change in OH has a positive effect. What about other gases? Nitrous oxide, we are uncertain; CFC11 and 12, both negative; HCFC22 (which is being talked about as an immediate replacement of CFC11 and 12) has a very high global warming potential of 1600 (relative to carbon dioxide) on the present basis, its indirect effect is also negative; HCFC134A (which is now the target in many countries for the final replacement after a number of years), we do not know any negative/indirect effect there, but its global warming potential is also large, about 1200. So what are we talking about? On one hand, we are talking about compounds with reduced ozone depletion potential but on the other, we are introducing compounds with appreciable global warming potential. Does it (that is, one reduction producing another increase) solve the problem? One has to look at that. So indirect effects become increasingly important. The consequence is that we will have to take into account the change in one at the cost of another. And the policy implications of these have to be carefully thought about because it is scientifically a dicey area.

The next point I would like to mention is carbon dioxide or carbon content, whether it is fossil fuels or biomass burning. Now the comment that was made from the External Affairs Ministry about the per capita basis. The emission in terms of carbon from almost all developing countries, including India, is 0.2 tonne per capita. The global average is 1.2 tonne per capita, something like six times as much.

Now, if you take the cumulative values from 1950 onwards, the contribution from India is 1.6% of the overall. Now what sort of policy does one take? At 0.2 tonne per capita, we contribute one-sixth of the global average. Should we consider the historical emissions? After all, we are talking about molecules that have a very long lifetime. What is in the atmosphere now has been there for a very long time. So should one not take the historical emissions? Also, different greenhouse gases have different residence times. How do we handle that? In one case, it is 100 years and in another case, e.g. methane, it is 11 years. For sulphur dioxide or sulphates it is much shorter: a few days, sometimes a few hours. How do we handle the relative values of these?

The next point is about methane. I understand that Professor Menon mentioned, on an earlier occasion, the different values that we got. We got into the field for a different reason. We had been measuring emissions from biomass burning for a different purpose as a part of the Indian Middle Atmosphere Programme—from the slash-and-burn agriculture in north-eastern India. We had also made some

measurements about emissions from paddy fields. Global estimates for methane from all sources are of the order of 500 teragrams (500 million tonnes). Of this, 100 teragrams is attributed to rice paddy fields. When we saw that the value attributed to India was 37 teragrams, we made a quick calculation on the basis of the measurements we had and found that it can be under no circumstances as large as that. Something of the order of 3 or may be 5. So we launched a campaign, (Rice Campaign 1991) covering 15 to 20 places all intercalibrated. We had joint calibration efforts also with Japan and Australia. The value still is 4 teragrams. So from 37 we have come to 4. This alters China's earlier values, which have been quoted, or the original estimates of California that have been quoted: their values are high; Indian values are low. The values that are high are based on certain conditions, i.e. conditions of water-logging, conditions of the system in which the redox potential has to have a certain value, conditions of high carbon content. The data indicate lower emissions of methane from rice fields than previously estimated. Also, recent studies of methane emissions from rice agriculture, in particular from Japan, India, Australia, Thailand, and China, show that the emissions depend a great deal on growing conditions and soil characteristics. While the overall uncertainty in the magnitude of emissions from rice agriculture remains large, a detailed analysis now suggests significantly lower annual emissions than reported by the IPCC in 1990. So here is a case study where separate measurements, made in different countries under different conditions, may change the inventory and change the whole concept of what is important and what is not. Therefore, methane to us is not an important parameter. The total global estimate that we have now would not be more than 20 or 25 teragrams out of 500. Therefore, the technology strategies or policy strategies we adopt will have to be different.

The final comment relates to the scenarios that we use. There has been the 'business-as-usual scenario'. That is now dropped. There are six scenarios that assume different population level, energy usage etc. and also scenarios of increases in many of the greenhouse gases. But an unexpected change, such as the increase in tropospheric ozone, will upset many of these. So the scenarios become very important not only in deciding the calculation procedures, but also in deciding what technologies one should use. For example, population is a major parameter in these scenarios; energy is another major parameter. Therefore the whole concept of technologies or options that one takes in regard to population or energy-mix becomes important. Technologies to control emissions of greenhouse gases become crucial while deciding which greenhouse gas should be the target for a particular country: carbon dioxide or methane, and which particular sources. For example, in the case of Brazil, the targets should be reduction of biomass burning and emphasis on forest conservation and not in terms of carbon dioxide or the fossil fuels.

To sum up, the scientific base of many these parameters, whether it is greenhouse

gases or the measurement techniques of the greenhouse gases or making the inventories, is fairly sound in India. Many of these are now very well standardized. There are new facilities available that give a new dimension to this, e.g. the Indian Remote Sensing Satellites 1 and 2 or the new MST (mesospheric, stratospheric, tropospheric) radar that has been set up near Tirupati, which are major components of some of these systems.

The BBC and the environment

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It is very kind of you to invite me to be here, and I am very happy to speak on behalf of the BBC. It is also an unusual occasion for me because usually I find myself batting against people, when I speak in India, who attack the BBC for always presenting a dismal picture of India—which I deny that we do—whereas today I am going to try and suggest that at least in this area we have a duty to present a dismal picture of what is happening in the developing world. So that makes it rather unusual for me.

I have just been talking to Dr Menon; he has pointed out to me the startling fact which we realize within the BBC, but he has got independent research to confirm this, that the media were the last to jump on what I might call the environmental bandwagon. That we became aware of these issues later than anyone else. And talking to my colleagues in the BBC in order to prepare myself for this lecture they all said that it was only the last five years or so that the BBC had really started to regard the environment in general as a very important subject. One person who is the editor of our environmental strand called *Nature*, Amanda Tennison, said that she believed one of the major events which awoke the public and the media to the environmental problems was the Bhopal gas disaster. From that we went through other international disasters, including of course Chernobyl. Another factor which many people in the BBC I have spoken to feel has heightened awareness is the lifting of the Iron Curtain and the growing reports about environmental degradation and the state of the environment in the countries of Eastern Europe. All these, and of course, issues at home, domestic issues, some people would believe brought the environment into that category of news stories which we journalists sometimes describe as sexy. It is like human rights, like feminist issues—an issue now on which you can attempt to sell stories to editors.

But there is no reason for environmentalists to be—and especially those in pressure groups—to sit back and say that their job is done; that the issue has now

been sold to the media; because there are always many other issues competing for the attention of organizations like the BBC. Someone was telling me of a recent survey which showed that on the one hand journalists felt that the public was getting tired of environmental issues and that the journalists themselves were suffering from environmental fatigue. Whereas in fact it was untrue. The survey suggested that the public was anything but tired of environmental issues. So this is one factor that you should all bear in mind when you think of the media that you have not won the battle yet.

The BBC reacted to the awareness of the environment in a variety of different ways. One was by producing a new slot, as we call it in television, a slot called *Nature*, which makes 16 films a year on environmental topics, some of which have been very highly appreciated. We are very much involved in the whole one world movement and in the collaboration between public service broadcasters from many different countries, not just Western. This year's one world is going to be six weeks' worth of programmes leading up to the great United Nations Conference on Environment and Development. Apart from these specific strands we have appointed now environmental correspondents whose duty it is to cover the environment and, harder still, to make sure that environmental stories get on the air. One of those is Ian Breech, our television correspondent, and he recently reported to his bosses in the following terms. He said: 'Environmental concerns, far from being at the top of the political agenda, are a low priority in Whitehall and Westminster and this is reflected in their media coverage. Environmental stories almost invariably are put at or towards the end of news bulletin running orders and are therefore the most vulnerable and droppable as other news items, principally foreign stories, crowd in. So that is the experience of the BBC environment correspondent, that partly because of editorial views but also partly because these matters are not very high on the political agenda, it is very difficult to get environment stories into news bulletins. Here I would just make one small point which you might like to think about and that is that in my view there are in the electronic media two really quite different types of coverage: the documentary coverage, which I think we do quite a lot of, and the news coverage. The difference between the two is that the news coverage will get you a very much higher audience than a documentary will do and somehow or other, although it is much shorter, it seems quite often to stick in people's minds more. It has a greater impact. Therefore it is no good again patting yourself on the back if you are environmentalists and saying we got this very good documentary shown, if you are not getting things into the 9 o'clock News in England or the 10 o'clock News on ITV. To get the environment as a major matter of journalistic concern in League Division 1 rather than in League Division 2, is still a battle which you environmentalists have to fight.

I just wanted to speak a little bit about India and the BBC and this problem

of the environment because I think that it is very very important. When I was talking to Amanda Tennison, the editor of the programme *Nature*, she made the point to me that there is a direct link in the views of Western journalists anyhow between environmental problems and the developments in the Third World. And there is in her view an urgent need for the Western world to realize and understand the environmental problems that are being created by the development pattern being set in countries like India. India is obviously a very good example of this because it is a fast developing country; it is a country with a considerable industrial base; it is a country with a vast population; and of course it is a country with great environmental problems.

But here we come to a problem. Does India want to reveal to the world the state of its own environment? Or are the officials of the External Affairs Ministry and the Information Ministry only too anxious to try and hide these problems? I think the record of India is very much better, obviously, than the record of China or many other developing countries. But I still think that India has some way to go before it can say that it honestly does everything it can to encourage true, honest, and accurate coverage of environmental issues in this country. I think that is something which India and Indians have to think about, because if your environmental problems are linked with the economic activities of the developed world, if there is a link between the whole thing, then surely you have to get the message across as to what is happening in your own country into the developed world.

I think the other thing which is tremendously important in India and indeed throughout the world, and I find this sometimes in India, and that is the one risk of the environmental movement, is that it will either oversell issues or sell issues before they have been properly researched. Because of that they become what I might describe as dud issues. All of you are aware that there are more than enough people, industrialists and others with vested interests, only waiting to knock down journalists and environmentalists to prove that it is all a lot of emotional nonsense and to destroy the environmental movement. Therefore it is very very important indeed that all environmentalists, specially in countries like India where there is great deal of opposition to the whole environmental movement, should not oversell stories nor should they prematurely sell stories. One of the most interesting examples of pressure groups amongst the developed countries is undoubtedly the Greenpeace Movement. My colleagues in London feel that on the whole the issues which they have sold have been valid. They have learnt to respect the Greenpeace Movement. It is very interesting that on today's BBC news when we had a little story about the anniversary of the American-Iraq War or the West-Iraq War, the BBC Defence Correspondent quoted or had the voice of a Greenpeace spokesman on that speaking about the war's environmental consequences.

So it shows that if environmental groups behave responsibly then they will get very much more air-time and greater respect. Because no journalist wants to feel let down.

To sum up very briefly what I have tried to say, it is firstly that your battle is not over, that the environment is not on top of the journalistic agenda—it is nowhere near top of it. Secondly that in the developing countries if they believe, as I am sure they do believe, that these problems are interlinked there must be an openness to journalistic investigation of their environmental problems. Thirdly, there must be on the part of environmentalists a great sense of responsibility and a sense of caution in the campaigns they run, the stories they run. I am all in favour of these campaigns and all in favour of these stories and so are my colleagues in London. We are all very, very much aware that without these sort of pushes from these pressure groups we would not be able to do our job. We are also well aware what the conferences like this do to draw the attention of even our most parochial editors to these problems. So we would very much like the environmental movement to put as much pressure as it can, provided it is responsible and scientifically accurate.

Media perceptions on climate change

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I am speaking of journalists like myself and, I suspect, my colleagues throughout this country, but I think there are some basic truths about journalists everywhere, and that is we know a little bit about everything but nothing about an issue in any depth.

I think the global warming issue has highlighted this especially for us in India and I count myself among the first and foremost culprits. We were far too quick to jump to conclusions, far too quick to pick up data as they emanated from the West without analysing it. If this is a failing, I think it is to do with the fact that not many of us have a science background. We have come from a background in the Arts and the Humanities and for us something like the greenhouse effect is some kind of esoteric phenomenon. I must confess that listening to the deliberations of this conference, especially on the first day, we were taken into that very rarefied atmosphere of models and parameters and prescriptions and a lot of seemingly conflicting data, which does not make the work of journalists like us any simpler. Add to that the fact of very sanitized pronouncements by policy makers and the whole question of global warming and the greenhouse effect gets even more and more problematic for generalists and journalists like us. So we have, I think, to carve our own kind of path, our own niche, in this area and try to sift fact from fiction, fact from dubious interpretation.

At the very beginning, when the first indications of the global warming process took place, we were all swamped by the doomsday aspect of it—the fact that our immediate neighbours like the Maldives might altogether disappear and Bangladesh, at least a very large part of it would be inundated, as also our own coastal cities. I do not think any of us looked at the connections between this and the larger process of environmental degradation. One who did was Anil Agarwal, who, I must remind all us here, is, was and will be as much a journalist as a researcher. These connections, I think, did not actually appear to us in their real form. Very soon

we were confronted with the question of the Montreal Protocol in 1990, at the London Conference, which Mrs Maneka Gandhi attended. Again, there was a lot of rhetoric and I must confess again that London correspondents of Indian newspapers did not report this al all adequately. Our only source of information was Western correspondents who picked up the rhetoric that was voiced in London, and we dutifully echoed some of that rhetoric. It was to our minds the first time that the divide on North–South issues became clear on this specific subject. The fact that, for instance, the two biggest countries in the world, China and India, only consumed 2% of the world's CFCs (chlorofluoro carbons), and that we have a vision of the future increase in living standards where we too can hope for refrigerators and air-conditioning and all the other devices these wonderful chemicals provide us with. The fact that there was this vast divergence of opinion and positions on these issues, I think, was made manifest to us. But again because of our shoddy homework, we did not realize that behind the rhetoric of this stand, at least speaking for our own country, we were very sheepishly being prepared to sign on the dotted line and accept the Montreal Protocol, and accept those limitations. Under the very illusory promise of funds from this facility (I think it was 240 million dollars), a fund was created at the London Conference, we were supposed to switch over to benign technologies that did not resort to CFCs.

A study conducted for the Government of India by an independent consultant —I think in fact it was a British or an American consultant—put the total cost to India for switching over to non-CFCs in its refrigeration and other plants at one billion US dollars, taking into account the increase in demand for goods that would inevitably take place with increasing aspirations of the people. So if India and China's share was something like 40 million dollars out of this very small fund and if our own needs were placed at one billion, it was very clear that the benefits of this fund were somewhat illusory. But again, all of us did not harp on this enough. I think we ourselves did not look into our own situation in India. Our business journalists did not look at the fact that there were five producers of CFCs within our own country. In fact one of them was about to export some technology to Iraq before the Gulf War began.

So we did stop short in these investigations, which is not to say that we are as much polluters as the big producers of CFCs. But we should have looked at our own compulsions and our own problems. We, for that matter, did not look sufficiently at the fact that the technology that does exist in the western world for switching over to non-CFCs is held by companies such as Du Pont. We are quite sure that Du Pont is not going to part with this technology without someone paying for it. And who is going to pay for it? These are all questions that we should have been really looking at.

Then came the World Resources Institute. My colleague Anil Agarwal has not

named the institute, but I shall do so. The World Resources Institute came out with those figures and all of us somewhat uncritically accepted them as indicative because they had the stamp of Western science and Western research. We accepted these figures for pollutants and polluters for India and China as well.

India came out the fifth biggest emitter of greenhouse gases in the world. It then fell upon the Centre for Science and Environment in Delhi to critique this, as we have heard today. Again, we in the media were content with merely parroting that critique without doing our own analysis or trying to cross-check these figures, examining all the political and geo-political questions that this gave rise to.

If I began halfway through this presentation by knocking the media, let me immediately—with the facility with journalists enjoy—switch track and come to its defence.

I must take some issue with Mark Tully (of the BBC) here when he says that the media in India have not done a sufficient job of highlighting the problems of the Indian environment; I think the work of the Centre for Science and Environment in general, and the two *State of India's Environment* reports specifically are second to none anywhere in the world. It is the work of professional journalists and researchers who have taken from NGOs and people from all parts of the country their grass-roots experience and edited them in a professional way to highlight exactly the kind of environmental crisis with which we are faced. In that sense, the media in this country have anticipated many of the problems we are now faced with as a global issue. Take just the energy issue; the fact of the declining amounts of firewood per capita and the tremendous amount of energy being spent by women and children on collecting fodder, water, and fuel, is something that has been highlighted to a very large extent. This is the contribution of the media because unlike scientists, unlike policy makers, we in the media have the facility to connect all the time. We are able to go to different disciplines and connect them in a meaningful way.

Some years ago, I did some work on the effect on the Taj Mahal of the Mathura Oil Refinery. I was quite astonished to find the vast array of scientific expertise, which we have also witnessed on the Indian side on issues of global warming. I was quite amazed to see that a question like the effect on the Taj of pollutants, the sulphur dioxide from the Mathura Refinery, would involve meteorology, some mathematics, some chemistry, archaeology, and several other disciplines. And when the Government formed a committee to investigate whether Indian science could tackle this question and come to some understanding of it, the consultant, who was an archaeologist, travelled the length and breadth of the country and came to the conclusion that we had all the expertise that was needed. For instance, to find the impact of the desert winds on the sandstone and marble structure of the Taj, there was research done in Hyderabad by the Air Force establishment how, when a helicopter lands in the desert, the blades of the helicoper on are pitted by the impact

of sand—the same technology could be applied to studying the impact on these stones.

So we possessed all the research and the expertise but we did not possess any kind of fusion of these disciplines and that is why the entire study was handed over on a platter to an Italian consultant. It is our experience that we did not learn very much from the study except what the two or three Italian archaeologists, who had experience of Venice, had to teach us. So I think the media do here play this very important role of connecting all the time—connecting people, institutions, and places in a very meaningful way. When one looks at global warming, one sees that if people are always seen as the problem, people surely are also a large part of the solution. This is where I think the media can interface between the scientific and bureaucratic community and the people at large in what we are doing. We have been talking about, for instance, equity. If you look at climate change, and if you see figures being put out now of a carbon tax at something like 50 dollars per tonne of carbon emitted, we would come up with a global fund of 280 billion dollars, which amounts to at present day level something like 240 dollars for every American and 9 dollars for every Indian. So the questions of equity are being addressed and I think we in the media should try and highlight these questions so that before any agreements are entered in the international process our voice is heard.

Let me conclude with the question of population, which is constantly referred to in such deliberations. Our own study, after travelling to various parts of the country, shows us that this is entirely connected and cannot be de-linked from the issues of the distribution of resources and of energy specifically. Most importantly, if we can survive, if we can ensure the survival of a child until adulthood, that would automatically make the population take care of itself. For a child to survive until adulthood, we have to provide enough food, energy, building materials, all the things that make for human well-being. And how we provide that is a question not so much of funds from any facility, national or international. We in the media have begun to teach ourselves this and re-learn the process. It is a matter which is as problematic as it is simple. It is only a matter of changing the way we relate to ourselves and our natural resources. In other words, if we begin to manage our common property resources in an equitable manner, then we will take care of our own environmental problems and hopefully, so will the rest of the world.

Policy and awareness in the UK

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The event that marks the initiation of wide interest in climate change in the UK is commonly held to have been a speech that the former Prime Minister, Mrs Thatcher, made to the Royal Society in September 1988. In it, she spoke of 'a massive experiment . . . which we have unwittingly begun with the planet itself'. This speech marked the beginning of a period of intense scientific, political, and lobbying activity that has exercised fundamental changes on government policy and energy strategy. Whether intended or not, the effect of the speech and the wide publicity that followed it was to boost the membership of environmental groups and give the Green Party an unprecedented 15% share of the vote in the 1989 elections for the European Parliament.

The importance of the climate change issue for the UK Government cannot be underestimated. Prior to 1988, the UK had been criticized for its unresponsive attitude to many environmental problems. Mrs Thatcher's Royal Society speech marked the beginning of a new pro-active approach to environmental policy. Climate change has emerged as the flagship issue of the government's new environment programme.

Public awareness

The IPCC (Intergovernmental Panel on Climate Change) Working Group report on response strategies talks about 'ignorance, apprehension and confusion, concerning climate change. A survey carried out for the Department of the Environment in 1989 paints a picture of British attitudes that partly confirms this view. The enormous impact of the publicity given to environmental issues in 1988-89 is illustrated. Without being prompted, 30% of people mentioned that the environment was one of the most important problems that the government should be dealing with. When the same question was put in a 1986 survey, only 8% of people had identified the environment as a priority issue.

The abstract nature of the threat of global warming is also illustrated. In spite of wide publicity, global warming was the least well-known of 21 environmental problems presented to people. It was not one of the five key environmental issues which more than half of the sample said they were 'very worried' about. Chemicals put into the rivers and sea, dirty beaches and bathing water, radioactive waste, destruction of the ozone layer, and oil slicks from ships were people's prime concern. However, 72% of people said that they did have worries about the greenhouse effect.

The remoteness of the global warming threat conditions people's perceptions of their own and others' responsibilities. Interestingly, less than one in ten of the sample said that those causing global warming ought to do something about it. This was the job of the government according to 24% and of international bodies according to another 59%. Another recent survey conducted by CEED (Centre for Economic and Environmental Development) shows many misconceptions about the ways in which individuals can influence emissions of greenhouse gases—using lead-free petrol to reduce global warming and recycling paper in order to conserve tropical forests are examples. A broad willingness to take actions that would improve the environment is evident. But the environmental benefits of specific actions are not always well understood.

Government policy

The government's policy on greenhouse gas emissions was announced in early 1990. Britain is prepared, if other countries take similar action, to stabilize emissions of carbon dioxide at their 1990 level by 2005. In October 1990, a joint meeting of energy and environment ministers set the EC (European Community) the demanding target of stabilizing carbon dioxide emissions by 2000. The contributions of countries such as Germany, The Netherlands, and Denmark, which are aiming at emission reductions of 20-25% by the first decade of next century, will assist the EC towards its target.

Britain's environmental policy became inextricably linked with that of the EC during the 1980s. The Act of Political Union, agreed in December 1991, creates even closer ties. Most EC environmental measures can now be decided on the basis of a qualified majority vote in the Council of Ministers. An important exception will be measures involving tax changes.

The EC strategy

EC strategy is relevant because it will frame the scope of UK measures. There are three basic elements:

- A package of traditional regulatory measures of the type used following the oil crises of the 1970s. These may include research and development activity, promotion of renewable energy, voluntary efficiency im-

provement agreements with specific industrial sectors, standards for electric appliances, lighting and building insulation, and improved fuel efficiency for motor vehicles.

- A combined energy/carbon tax levied at $10/barrel of oil equivalent, phased in gradually from 1993 onwards. 50% of the tax would be levied on the thermal content of fuels and 50% on the carbon content. Another feature of the proposed tax is an exemption for energy intensive industry pending similar measures in the US and Japan.
- Complementary national measures.

The Joint Energy/Environment Council that met in December 1991 asked the European Commission to produce concrete proposals based on this outline strategy. By far the most controversial element has been the proposed carbon/energy tax. Understandably, OPEC (Organization of Petroleum Exporting Countries) has attacked the measure. It has been criticized within the EC for its possible effects on low-income households and the competitive position of European industry. Others say that the proposed exemptions for energy intensive industry fatally weaken the tax proposal. The relative energy and carbon components of the tax have been disputed. France, with a large nuclear industry, would favour a pure carbon tax. At the other extreme, Ireland, which relies heavily on coal and peat, would prefer a pure energy tax. The fate of the tax proposal is being watched with keen interest.

The UK strategy

The UK's overall environmental strategy was described in the White Paper, *This Common Inheritance*, published in September 1990. Climate change occupied a prominent position within this document. Environmental groups criticized the White Paper, with perhaps some justification, for the lack of concrete measures aimed at cutting greenhouse gas emissions. However, preparation of the document has sensitized all Government departments to the fact that the environment must be integrated into other policy areas. The White Paper also represents a base level below which policy ambitions cannot slip. More specific policy measures are now under development. Progress has already been monitored through a published first-year progress report.

Government policy gives considerable emphasis to information, education, and motivating industry and private consumers to take actions that will reduce greenhouse gas emissions. The Energy Efficiency Office, which had been run down during the 1980s, has been re-expanded. In late 1991, a three-year, high-profile publicity campaign involving full-page newspaper advertisements began. These alerted the public to the risks of global warming and pointed out ways in which householders could reduce energy consumption. Coupled with a high level of 'image' advertising

from the nuclear industry, the gas industry, and electricity companies converting from coal to gas, there can be few in Britain who do not, by now, know about the dangers of global warming.

On the industrial side, the Government has charged an Advisory Committee on Business and the Environment to assess the contribution that industry might make to greenhouse gas reductions. For its own part, Government has created a Ministerial Group on Energy Efficiency, which is considering policy initiatives and is developing an energy efficiency campaign within government buildings.

The emphasis on education and information partly reflects the flavour of energy policy over the last decade. It also reflects the reduced scope for the UK to take independent regulatory measures as its economy becomes more integrated with those of its EC partners. Among the specific regulatory measures that the UK is pursuing are quotas for renewable energy for the privatized electricity companies and the assessment of tighter building regulations. Britain is trying to persuade the EC to adopt a system of efficiency labelling, and possibly mandatory standards, for electrical appliances. It is also proposing a system of efficiency targets for new motor vehicles, supplemented by a system of tradable credits for manufacturers.

The work of non-governmental organizations

NGOs (non-governmental organizations) have played a crucial role in increasing public awareness about environmental issues in the UK. This was particularly true prior to 1987-88 when policy interest in the environment was at a low ebb. With government now taking an active role in promoting awareness of climate change, the NGOs' role has become more focused.

The structure of the environmental movement in the UK and recent developments in the focus of its activities form a useful background for assessing its contributions on the climate change issue.

The environmental movement in Britain has two broad components. British concern about the environment is often argued to rest on a love of landscape and heritage. There are a large number of well-established environmental groups, some with extraordinarily large memberships, which focus on these issues. The National Trust, founded in 1895 and with almost two million members, is a prime example.

On climate change, the greatest degree of activism has been displayed by the more modern environmental groups, such as Greenpeace and FoE (Friends of the Earth), which began operating in the 1970s. These groups have displayed a sharper campaigning edge having, until recently, operated outside the system. 'Direct action' was very much part of these groups' activities. Greenpeace has obstructed whaling activities, while FoE is still remembered for dumping large numbers of non-returnable bottles on the doorsteps of a soft-drinks company.

The greening of the Government has induced a change in the style of operation

of the modern environmental groups. Following a path trodden decades before by the countryside pressure groups, the modern NGOs are now being drawn into the wider policy community, not simply because of the way that they represent and influence public opinion, but also because of the expertise and insights which they can offer. Direct action has largely given way to constitutional action: sponsorship of research reports, evidence to Parliamentary inquiries, meetings with Ministers, and the use of the courts to curb polluters.

Climate change campaigning

The climate change issue illustrates well the new role of the environmental groups. The range of activities undertaken by NGOs falls into several areas:

- sponsorship of research reports that synthesize available information and package it in a form suitable for wider dissemination
- publicity and public awareness campaigns
- lobbying the UK government and the European community
- participation in international discussions.

UK activities are formally co-ordinated through the CAN (Climate Action Network). A pan-European Climate Action Network based in Brussels focuses on lobbying the European Community.

To illustrate, the activities of three different organizations—FoE, Greenpeace, and CRPE (Council for the Protection of Rural England), all members of CAN—are described.

Friends of the Earth

FoE (Friends of the Earth) is the most well-established of Britain's modern environmental NGOs. The central FoE organization is supplemented by a charitable trust that channels donations and a devolved network of 220 autonomous local groups. The local groups are one of FoE's fundamental strengths. They organize local campaigns on specific issues and may undertake practical initiatives such as recycling schemes. FoE has about 200 000 supporters making financial contributions.

FoE has taken a great interest in the global warming issue but has not established a separate climate campaign. Its climate activities are handled jointly by its air pollution and energy campaigns.

The air pollution campaign has handled the acid rain and ozone depletion issues and is well equipped to deal with the scientific and international aspects of the climate change problem. It has sponsored research reports on the definition of ecological targets (warming limits) that might be used to define the climate change agenda, the impacts of climate change in the UK, and the contribution of transport to greenhouse gas emissions. At the practical level, it has produced briefing sheets on

the practical measures that local authorities and individuals can take to reduce their contributions to global warming. In early 1991, FoE organized a Day of Action which involved a large press advertising campaign backed up by a wide leaflet distribution.

Climate change has sharpened the relevance of FoE's energy campaign. Its main objectives are the promotion of energy efficiency and renewable energy coupled with opposition to nuclear power. The energy campaign supplies practical advice on energy efficiency but also lobbies the Government for policy and regulatory frameworks that will promote environmentally friendly energy use. The recent privatization of the electricity supply industry has provided the focus for much of its recent work. Among the issues addressed have been:

- market impediments to efficient energy use: for example, the price regulation of the newly privatized electricity companies gives them incentives to maximize sales rather than encouraging energy efficiency;
- the implementation of least-cost planning, whereby electric utilities are encouraged to invest in energy efficiency on behalf of their customers; and
- the continuation and enhancement of the quota/subsidy system currently being used to encourage the development of renewable energy.

FoE's national activities are complemented by those of Friends of the Earth International which is tracking IPCC discussions and is attending meetings of the UNCED (United Nations Conference on Environment and Development) Preparatory Committee and the INC (Intergovernmental Negotiating Committee) for a Climate Convention. FoE International has also held meetings with NGOs from developing countries in order to discuss issues, such as equity and sovereignty, that underlie intergovernmental negotiations. These discussions are reported to have been 'lively'.

Greenpeace

Greenpeace has probably taken the highest profile on the climate change issue. A significant proportion of Greenpeace International's activities are located in Britain. Like FoE, Greenpeace has tracked international discussions in the run-up to the UNCED.

Greenpeace has decided that science is very much on the environmentalists' side. Much of its campaigning effort has been directed at marshalling evidence that will put pressure on governments and international bodies to set targets and time-scales for the reduction of greenhouse gas emissions.

Greenpeace UK has edited an inexpensive paperback book, *Global Warming: the Greenpeace Report.* According to Greenpeace, this report 'says what the IPCC—in order to be consonant with the warnings of its own scientists' Working Group

—should have said about how we must respond to the greenhouse threat'. The book consists of a series of papers by distinguished authors, grouped so as to reinforce the structure of Greenpeace's case about action on global warming. Briefly, the line of argument is as follows:

- IPCC has identified a real threat of global warming. There are huge uncertainties, but they are about how bad warming will be and how quickly it will occur. In particular, there are real risks of a runaway greenhouse effect.
- The magnitude of these risks demands that the 'precautionary principle' be applied to climate change policy. Measures to reduce greenhouse gas emissions should be taken in order to buy insurance against uncontrollable global warming.
- Greenpeace believes that it has identified major opportunities to reduce energy consumption, and hence greenhouse gas emissions, through measures that have a negative cost, i.e. the value of the energy saving is greater than the cost of the investment.
- Future energy needs should, as a matter of priority, be met by renewable energy sources. Nuclear power is rejected on safety, waste disposal, and weapons proliferation grounds.
- Integrated strategies and targets for the reduction of greenhouse gas emissions should be established.
- There should be a massive transfer of energy-efficient technology to developing countries in order to enable a leap-frogging of the energy intensive development route taken by the industrialized countries. A parallel re-thinking of aid and technology property rights would be required.

While working relationships have emerged between the government and NGOs, Greenpeace, the most competitive group, remains at arms length. The titles of the reports that it produces to influence journalists, scientists, and politicians reflect its style. Climate change related reports produced over the last two years include 'Why Britain remains the dirty man of Europe' and 'This common incompetence—the mismanagement of environment policy'. The latter refers to the Government's 1990 environment White Paper, *This Common Inheritance.* For its part, the Government has not included Greenpeace in a list of useful addresses for the public to contact for more information about various aspects of the environment.

Council for the Protection of Rural England

As a well-established countryside group, CRPE's interest in the climate change issue has been less direct than that of FoE or Greenpeace. Its interest is two-fold.

First, it is considering the long-term effects of climate change on the English landscape. How might it affect designated Areas of Outstanding Natural Beauty and Sites of Special Scientific Interest? What are the implications of agricultural adaptation to changed climate conditions? This concern has prompted CPRE to sponsor research on agriculture, crops and water resources from one the UK's leading climate impact research groups.

Second, it has a permanent campaign on energy and natural resources covering issues such as mining and power station development. Its energy position—strong support for higher standards of efficiency—has resonances with the climate campaigns of other NGOs. It has recently devoted a great deal of effort to the influence of the planning system on settlement patterns and the way in which these lock communities into long-term patterns of energy use.

CPRE enjoys a degree of political access greater than almost any other NGO. It was instrumental in securing amendments to the 1989 Electricity Bill requiring electricity generators to take account of the environmental impacts of their activities and the electricity regulator to promote energy efficiency.

CPRE is not tracking the IPCC process but plays other important roles at the international level. As a result of the respect it commands among its fellow NGOs, it has taken a leading role, via the European Environmental Bureau, in co-ordinating NGO input to the UNCED preparations.

Future action

The development of climate change policy in the UK and the EC has now reached a critical stage. Objectives have been set and the current task is to define the measures that will enable them to be met. Tensions between Government, industry, and NGOs clearly exist because of different levels of ambition about environmental objectives and different ideas about the types of policies that are appropriate. Nevertheless, there is a remarkable degree of consensus that an active climate change policy ought to be pursued.

The public has been sensitized to the issue and is evidently willing to take steps to change its behaviour, even if this involves financial sacrifice. The foundations of an active climate change policy have been laid. The next few months will test the real willingness of the UK Government, industry, and citizens to take tough measures.

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Human dimensions of global change: opportunities and choices

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Viewed from the standpoint of the needy and the vulnerable, most global changes present major threats which could be very difficult for them to cope with. Given the existing economic inequities and imbalanced institutional arrangements, the threats of sea level rise, more extreme climates and other changes in the planet's life support system would certainly impose additional burdens on the two-thirds of the mankind that already lives under considerable economic and ecological stress.

Yet, global change may be precisely the mechanism needed to introduce the modifications in the global economic and political structures that can lead to a more sustainable development in all countries. The opportunity exists, but the choices are difficult and must be made not only by those living in the developing countries but also by those, mainly the rich, who have a vested interest in preserving the status quo.

For the present purpose, I take 'global change' to be that which results when an action in one place has an impact in another, distant region. Often, though not always, global change is mediated by the natural environment. A reasonably complete conceptual framework must, however, also include other social, demographic and political mechanisms.

Although the initial insights into global change have occurred primarily from the study of anthropogenic changes in climate (stratopheric ozone depletion and atmospheric temperature rise), an increasing number of future global change issues will certainly include more down-to-earth issues such as loss of genetic diversity, pollution of the commons, resource depletion, large-scale deforestation, population growth and crowding, etc. Undoubtedly, we can expect increasingly frequent resource-based conflicts to occur locally and even regionally. In the case of some resources, such as fossil fuels, it is not unimaginable that conflict could even reach global proportions.

Undoubtedly, the major global change occurring today is the massive inequity being generated by the world's economic system and the consequent impoverishment of the majority of people. Although poverty is a condition that has existed throughout history, rapidly changing perceptions and expectations, instantaneous communication and growing mass awareness, and the accelerating gap between the promises of science and technology and the actualities of life in the village or slum make it unlikely that the present trends will continue to be accepted for long.

The possibilities of reacting to global change and the opportunities arising from a systematic treatment of these lie in a clearer understanding of the determinants of sustainable development and in identifying the changes needed to achieve its goals.

It has been shown elsewhere that for development to be sustainable, any societal activity must satisfy four basic criteria. It must lead to greater efficiency, greater equity, greater environmental harmony, and greater endogeneity.

By efficiency is meant primarily the use of processes that minimize the waste of any resource, including not only natural resources but also people and their skills.

Equity, in today's terms, primarily requires direct development action on poverty.

The exigencies of the environment primarily imply the need for activities that do not perturb the processes of nature outside their limits of normal recovery.

Endogeneity is equivalent to the concept of self-reliance at the local level, a capacity to identify and deal with the problems of life and to make rational decisions about these. Rationality in this context has to include both self-interest and societal goals.

The patterns of consumption and demographic growth have currently reached proportions that in many places certainly threaten the capacity of the resource base to sustain these indefinitely. Globally, however, society perhaps still has a little time to effect the changes needed to pull back from the precipice of a catastrophic failure of our life-support systems. These changes will have to take place within the next few decades, an extremely short period of human history.

To manage the changes needed to make development sustainable, the following five instruments of human development have to be significantly re-designed:

- Technologies
- Institutions
- Decision-making systems
- Knowledge structures
- Value systems

The issues of sustainable development are quite complex and require complex systems to manage them.

The route taken by the affluent nations to technology is, self-evidently, not sustainable. Technologies must now be far more resource-conserving, decentralized,

humane, and subservient to the needs of people. The entire R & D structure in developed and developing countries needs radical change, primarily to gear its thrust and results to the needs of those who have so far been bypassed by the fruits of modern science and technology. To achieve this, science and technology policy at the national level now has to be fundamentally re-designed to promote research and the applications of research that will lead to greater efficiency, equity, environmental soundness, and endogeneity.

Re-design of institutions at the international, national, and local levels is fundamental to the achievement of sustainable development. Decision support systems that permit societies to 'think globally and act globally' are virtually non-existent, and need to be created. In the new information society, it is now increasingly becoming possible to develop mechanisms for the participation of people in decisions that affect them and for more effective collaboration among experts who have the requisite specialized knowledge to design and manage complex systems.

To design the new kinds of decision-making systems needed, each society must have a clearer and more explicit picture of its goals (as determined by itself, but in the light of wider, global concerns) and the indicators of social development. To take society from its present state to the desired state in some agreed-upon time scale, decision-making systems must better understand the transformation functions (i.e. policy interventions) that are available or could be designed. These transformation functions can be extremely non-linear, counter-intuitive, and cross-sectoral. This area alone can provide sufficient research topics to keep scientists throughout the world busy for some time to come.

In addition to the changes needed in our choice and design of technologies, institutions, and decision-making systems, more fundamental and deeper changes will also be necessary in the knowledge structures and value systems that guide our thinking and action.

The disciplines of science and the ethical basis of our approach to development are currently far too deficient to take the imperatives of sustainable development. The concepts of the efficiency, equity, environment, and endogeneity will have to become the underlying paradigms of society, to be used as implicit yardsticks to measure change leading to the betterment of mankind.

What all this amounts to is that we now have to go beyond the dichotomies that have ruled our thinking in the past:

- New versus old (modern versus traditional)
- Big versus small (centralized versus decentralized)
- Private versus public (the individual versus society)
- Applied research versus basic research
- Social science versus natural science.

In fact, the whole divide between the West and the East, based on ideological positions of right versus left, can no longer hold any solution for the future. The four 'E's of sustainable development can be justified on purely resource and ecological grounds and no longer essentially need religious or ideological support, whether Buddhist or Gandhian or Marxist or neo-classical. Their implementation may well be strengthened by such ideological underpinnings but their ecologically-based logic transcends the existing conceptual frameworks of social organization.

Above all, current economic theory is in need of basic rethinking, not merely an occasional fine-tuning. It has to be made dynamic to treat systems that are essentially in a state of non-equilibrium. Perhaps more important, the basic objective functions and the tools of both neo-classical and Marxist economics have to be re-designed to take into account all the issues on equity (across time, space, and class). It must now incorporate concepts such as meaningful work, variety and complexity, resilience, and cross-sectoral impacts. In order to achieve these goals, many of the existing theoretical frameworks and the financial institutions will have to be scrapped and replaced by totally new ones based on the paradigms of sustainable development.

These new paradigms will also have to be supplemented by new approaches to the arrangements under which scientists and decision makers have organized their resources. The issues of sustainable development have to be formulated in a manner that addresses the need for self interest among those who make major decisions. For the public to be more closely involved in these decisions, new methods of communication are needed to increase the transparency of the issues as well as of the decision-making processes to increase the participation of those affected by them.

The role of the nation-state and, particularly, the concept of national sovereignty will necessarily change over the coming decades in the face of emerging resource issues that transcend national boundaries.

Some fundamental assumptions, currently accepted unquestioningly, such as intellectual property and the role of creative endeavour are in need of radical change, in a world whose survival depends on massive innovation and its rapid and widespread application.

The nature of research itself will have to change, increasingly taking on the aspects of 'action research' to be shared more closely with the objects of research and breaking down the traditional barriers of basic versus applied and natural versus social. The social science community will have to build a far greater degree of self confidence than exists today in the value and quality of its enterprise.

Perhaps most important, research must now address the complex issues of sustainable development with genuinely multi-disciplinary tools. These will require new kinds of institutional frameworks capable of facilitating collaborative research.

The role of the professional lies at the very heart of any science-based effort to cope with global change. As the custodian of specialized knowledge, the

practitioner in any field has a responsibility to provide early warning, identify the major variables, and help design alternative solutions to the problems facing mankind. In doing so, the scientist, engineer, architect, doctor or lawyer has to follow principles akin to the Hippocratic oath as an expression of their responsibility to society and to their profession. The education system and the reward systems will, of course, have to be re-designed to encourage this trend.

Global change will unquestionably take place at an accelerating pace over the next few decades. Many variables in addition to the ones of current concern (e.g. climate change) will have to be dealt with and, unquestionably, the systems of governance, research, economic transactions, decision-making, and education are in for substantive changes as a coping response. A collective, pre-emptive effort to make these design changes is, in my view, far preferable—even if somewhat inconvenient to those of us who have a lifetime of commitment invested in them— to having them forcibly and sub-optimally imposed upon us by the necessities to react to this global change.

Whose pollution and who pays?

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First let me introduce myself. I came into the environmental community when Friends of the Earth was founded in the United Kingdom twenty years ago. I was by degree a biologist and by profession an accountant. Friends of the Earth was involved in environment in the North. In 1976 I joined the International Institute for Environment and Development: one reason being that Barbara Ward, its president, was bringing the two lines of thought into one harmonious concept, namely sustainable development. It is concerned with the South.

I feel a little squeezed today because I have old friends in India and in this room who are currently in strong disagreement with other colleagues of mine in North America. Rather than try to reconcile each, I thought it would be more useful to address some of the points which were raised this morning. As a result, I will depart from the text that I came with. If I had stayed with it, the disagreement would only deepen.

I need to address four points:

- What in fact do environment and development groups in Europe now stand for? I want to relate to them because they know that they come from the part of the world that is responsible for 75% of greenhouse gas emissions.
- Secondly, I want to try and relate the climate agenda to what is going on in the UNCED (United Nations Conference on Environment and Development) process.
- Thirdly, coming out of that, what can we realistically expect from that process? Of course, much will be left to do afterwards. But it is very important that we have an idea of what is likely to emerge in realistic terms now. If we do not, there will obviously be some very frustrated people around.
- Fourth, I do want to refer to the controversy over WRI's (World Resources Institute) analysis of who is responsible for the 'greenhouse'

> and for the warming we may now be experiencing. Certainly WRI was wrong not to take account of historical responsibilities for world climate change. And certainly they were not using good data when it came to vegetation change. CSE's (Centre for Science and Environment) analysis was far more to the point but that too had its weaknesses. Please do not let anyone believe that the world is ready to accept a global formula for allocating future costs and responsibilities over the greenhouse issue. It is not. The political eye in OECD (Organization for Economic Co-operation and Development) is on other matters elsewhere right now as I will explain later.

What then of the organizations in Europe that make up its NGO (non-governmental organizations) community? Of all the points that could be made, one is that they have surely been a success. In twenty years they have raised many issues, including climate, high up the political agenda. I think it has been quite remarkable how successful that has been. The environment movement has caused a renaissance in intellectual thought as well; particularly in the application of natural science to the political process and, more recently, in changes to economics as set out by the various schools of environmental economics. But organizations in the North are still more concerned with the symptoms of environmental change rather than the causes. And in the case of climate change, we see the best and worst of it. At one end we have an organization putting pictures in the press of St Paul's Cathedral half under water and at the other, serious attempts to find least-cost solutions to our dilemma.

The former groups are trading on fear and would not last long; the latter have the very real conservatism of European voters to contend with. We must not forget that support for environmental issues is still essentially NIMBY in character. That means Not In My Back Yard. And the response of politicians is still essentially limited, with notable exceptions, to NIMTO (Not In My Term of Office). So we still have much to do, as was said this morning, to bring the public to a wider view of environment as well as development.

Having said that, there is a remarkable coming together of the environmental and development groups around the issues before UNCED in general. For the North, the particulars of the climate debate have begun to drive home just what sustainable development means. It involves the lifestyle of each and everyone. The ideas that underpin it are gathering support and it is going to be politically interesting in Europe for a long time yet. I say in Europe because the situation is not so well developed in the United States where the reconciliation between environment and development concerns is not as far advanced at all.

What then is this consensus called sustainable development about? It means several things which go together. First, it means using resources—all resources—

more efficiently so as to avoid waste. This applies particularly to energy. Sustainable development means using renewable resources at a sustainable yield point. Sustainable development means maintaining bio-diversity and habitats. But, also, sustainable development requires equity within and between nations. It also requires the establishment of clear property rights. It requires a secure means for participation in decisions, democracy if you like; and sustainable development also requires a new economic paradigm in which economists take into account three forms of capital stock: natural, man-made, and human capital itself. Sustainable development is, in short, rapidly coming to be seen in Europe as the reconciliation between economic activities, protecting the environment and meeting social needs.

This is the political agenda of the NGO community in Europe. They are not really concerned with the climate change issue alone. In fact many of us think that the climate change agenda is so uncertain and so fickle, perhaps even a political fad, that we should be emphasizing other fundamental points (which should have been addressed long ago) before we tackle the minutiae of the climate change technofix.

That is the background; now a look at UNCED. It is difficult to avoid the conclusion that UNCED is absurdly rushed. It has a complex agenda to be negotiated in the UN style. The result is, I am sorry to say, likely to be a disaster. To start with, the initial resolution, which the governments could not agree upon unless it contained a bit of everything, is the most complex resolution we have seen on which to base a major international event. At its simplest, it is a nine-issue agenda with 21 processes involving more than 150 nations. And you cannot sit down in an open conference to negotiate a matrix of 9 by 21 by 150.

For a start, the diplomatic community cannot cope. The best way perhaps to describe the process to date is that it has been a sort of Open University course for diplomats in what environment is all about. They have an awful lot of learning to do, excepting, of course, everybody in this room. We are trying to arrive at some conclusions and policy responses before the attendance by Mr Bush, Mr Major, and Mr Gorbachev (although I am not quite sure if he will be going now) and so many other heads of state.

At the heart of this complex agenda we find *Agenda 21*. This is meant to be the agenda for sustainable development into the next century and beyond. But the attention is on the three new conventions. Soon it will be on the institutional arrangements. And last but not least is the financial resource question. All this should hang together as a piece. But unfortunately the people who negotiate climate conventions are not necessarily the people who know about development agendas. And the people who know about development agendas are not necessarily the people who know about financial resources. Take the UK, for example, where the weak links exist between the Foreign and Commonwealth Office, the ODA (Overseas Development Administration), The DOE (Department of Environment), the DTI

(Department of Trade and Industry) and so on. I do not think any of us really understood the far reaching nature of what is involved in the UNCED process. It is beyond the governmental community everywhere. If you go around the world and ask for an honest appraisal in the capital cities on 'How co-ordinated are your national positions on financial issues, development issues and environment issues?', you will find a very mixed bag of responses. This is tragic because the climate agenda should be intimately linked to the sustainable development agenda. A separation of them is merely to drive apart environment and the development issue. And we are not going to find international agreement unless those two issues are driven together. The solutions to each are largely synergistic. And certainly they have to be driven together in a way that is positive if we are going to see a doubling of overseas development assistance by the year 2000, as has been asked for, and if we are going to see an acceleration of technical assistance and perhaps even non-commercial technology transfers.

Apart from this complexity, the difficulties that the UNCED process is up against are threefold: first we do have, or consider we have, a recession in the OECD; second, we have a completely new foreign affairs agenda, with financial implications when it comes to Eastern Europe; third, we have an impossible position vis-a-vis the United States and Europe. I hope and pray that the latter begins to shift; may be now that Mr Sununu has gone, things will change. But the position at the moment is extremely difficult. Eastern Europe will be with us right to the conference and, I fear, so will the recession. In these circumstances I think it is extremely unlikely that we will arrive at solutions in time to so many line to line issues.

It is because of the mind-set of negotiators that I think we should now be looking for a process that can roll over much of the problem, much like the GATT (General Agreement on Tariffs and Trade), into a series of rounds where we have to pledge and review. If we move forward that way, rather than trying to do it all in 1992, the world will be much happier at the end of the event.

Now what are the motivations for whom to do what? First of all, let me look at the motivations from the point of view of the Europeans. Europeans are, it is quite true, very concerned about global climate change. But many are equally concerned about development issues. And I think that the linkage between the two should be made explicit in NGO pressure applied. It is only by keeping the two together that we have the remotest chance of getting enough political will behind the process to change anything. We have to argue that global security (that is global security in everyone's interest) includes the environment issues, the poverty issue, the democratic issue, and ultimately the peace issue. Unless we argue all these together we will not get sufficient head of steam in our capitals to make any difference. We now have to progress in 'salami slices' forum by forum, so as to see a more equitable world order. Not all can happen in Rio.

But from the South point of view it is quite clear that UNCED should be used as an occasion to clear up one or two things in the international system that have hung around for a long time. The first is the degree of automaticity of funding in international financial flows. It is not generally realized—at least not in my country—that since 1981, in real financial terms, we have reduced the OECD flows for the South by almost half (from 201 billion dollars to 111 billion dollars). Most of the decline is accounted for by private bank lending. Developmental assistance has remained more or less static in the period although it now represents 48%, or nearly 50%, of the flows as compared to 26% at the beginning of the decade. But when you take into account the interest payments on the debt, all these flows are net the wrong way. People in the North do not understand that. As the Indian community pointed out, we have to do something about it.

The second point we have to address alongside outflows, but *not* at UNCED, is the trading relationships as manifested in GATT. Here, we have got some movement. It even appears, on occasion, that the United Kingdom is quite happy to fall out with its European partners on this point in order to see a reform of the Common Agricultural Policy. We have to see a set of fairer trading relationships with the South before the end of the next GATT. Alongside concessional flows and trade issues, we also have to put right some background issues. For example, a determination to make the multilateral system work more efficiently. It really is sad that so many of the strategies agreed at Stockholm for the United Nations family have, frankly, come to nothing because the UN has been indulging in what may be described as a 'pissing match' with itself. Agencies are all too ready to pour scorn on each other's efforts and generally to try to get in the way. It is improving but for at least ten years, the level of dialogue and co-operation in the UN was at a low ebb. It seems to me that we all deserve a UN that works co-operatively and efficiently. I think that is most decidedly a requirement if the outcomes of UNCED are going to be constructive.

But really that is not the essence of my point today. The essential challenge is to release a new synergistic effort on environment and development through Agenda 21 *and* the climate convention. The Brundtland report, and much since, was clear on the conditions required for sustainable development. We have to move as rapidly as we can to national sustainable development plans in which all aspects of government are involved and which then have the incremental cost identified. These must then be met from existing and additional flows. It seems to me that if we have climate plans and sustainable development plans which are complementary, it should be possible to mobilize resources—from additional concessional fund flows to debt relief, trade relief, and private investment flows. In the case of India, most of this will be internal finance but by no means all.

What do I expect to see coming out of UNCED if we all do really well? The

first point is that we should get a commitment to 0.7% of GNP for overseas development assistance by a specific date. For my own government that is nothing more or less than a timetabling of an existing commitment. That should be put back on the table with a reaffirmation of commitment—not this year, but certainly within the foreseeable future. Increasingly, I think we should also see Europe agreeing to write off sovereign debt against the Trinidad terms, something, I must say, that is moving well in the UK and elsewhere.

From the North, we also need a commitment to stabilize carbon dioxide emissions by the year 2000 and, after a review no more than five years hence, a move to reduce emissions further *if* the case is made. In other words, take it bit by bit. But we certainly need an OECD commitment to stabilize carbon dioxide now.

We also need an open-ended incremental cost fund—in other words, the GEF (Global Environmental Facility) revised. However, I do not want to see the World Bank led into yet another gravy train as the outcome. Many of the demands that are being made for a more accountable and open-ended fund should be followed through. Then we want to see *national* sustainable development plans to put *Agenda 21* into effect backed up by a co-ordinated UN. And finally, I would like to see more emphasis going into mobilizing the private sector, in which I include the NGOs. But the private sector for profit is important too. Work going on at present indicates that we are going to see some significant steps forward in that regard.

So, to return to the question I was meant to answer on today's agenda, I think, on the whole, that the North has to pay the price for global environmental change. But certainly not everything is perfect in the South. There is plenty of room for improvement within the UN. And if by taking the thing in salami slices we can match new resources to new commitments and to new efficiencies, then I think we can make progress. But it would not be helped by a set of stand-off and rhetorical positions. In the end it comes down to plans, incentives and people—*all* people.

Thank you.

Legal and institutional issues arising out of the proposed Framework Convention on Climate Change

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Introduction

The UNCED (United Nations Conference on Environment and Development) is mandated, by the UN General Assembly resolution[1] that convened it, to 'develop international environmental law', taking into account the existing international legal instruments.[2] Nine areas of 'major concern' are listed in that resolution, not in any particular order of priority. Climate change heads the list.[3] The preparatory committee established by Part II of the resolution has, in the course of deliberations on climate change, interpreted the mandate to mean the development of an FCCC (Framework Convention on Climate Change), supplemented by one or more specific protocols.[4]

The desirability of a comprehensive global convention as a framework for the protection of the atmosphere is now accepted. This is quite an achievement in itself. For, between 1945 and 1970 when the average global temperature had decreased, the international community was concerned with, and the scientists had initiated a spell of investigations into, the prospect of a coming ice age. Since then, however, prestigious organizations such as the Massachusetts Institute of Technology[5] and the World Meteorological Organization[6] have lent credence to the view that the burning of fossil fuels, deforestation, and changes of land-use have increased the amount of carbon dioxide in the atmosphere and that it has contributed to the warming of lower atmosphere which could pose a serious threat in the near future. Scientists from 29 countries have confirmed the global warming trends at the Villach Bellagio workshops in 1985-1987. The Toronto Conference on the Changing Atmosphere held in June 1988, with 300 participants from 46 countries, expressed concern over global warming and stressed the need for a comprehensive global convention for the protection of the atmosphere. On 27 January 1989, the UN General Assembly, at the initiative of the Government of Malta, passed a resolution (43/53) that formally

requested the UNEP (United Nations Environment Programme) and the WMO (World Meteorological Organization), through the IPCC (Intergovernmental Panel on Climate Change), to initiate action to formulate and identify the 'elements for inclusion in a possible future international convention on climate'. The General Assembly recognized in this resolution that climate change was the 'common concern of mankind'. The Malta initiative had titled the item as 'conservation of climate as part of the common heritage of mankind'. The General Assembly resolution also called for the 'identification and possible strengthening of relevant existing international legal instruments having a bearing on climate'.[7]

The UN resolution that convened UNCED itself contains the ingredients of a possible framework convention. The FCCC is required to cover the areas including climate change, depletion of the ozone layer, trans-boundary air and water pollution, the contamination of the oceans and seas and degradation of land resources, including drought and desertification. Horizontally, FCCC has to have a global, regional and national reach and the commitment and participation of all countries for, as the resolution affirms, 'the protection and enhancement of the environment are major issues that affect the well-being of peoples and economic development throughout the world'. FCCC is required to examine 'strategies for national and international action with a view to arriving at specific agreements and commitments by Governments for defined activities'.

The General Assembly resolution in reference postulates a political-economic philosophy and identifies in the process the causes of environmental degradation. The major cause, according to the resolution, of the continuing deterioration of the global environment is the 'unsustainable pattern of production and consumption, particularly in industrialized countries'. The resolution notes that 'the largest part of the current emission of pollutants into the environment, including toxic and hazardous wastes, originates in developed countries, and therefore recognizes that those countries have the main responsibility for combating such pollution'. The liability is apportioned according to the damage caused and the capabilities and responsibilities of the polluting nations. The developed countries are thus identified as the major contributors to the global environmental deterioration and are expected to bear greater part of the costs of repair; other countries are made responsible according to a mixed formula of damage-and-capability to restore the environment.

The developing countries are required to be treated in the FCCC with special care. The resolution makes it clear the 'poverty and environmental degradation are closely inter-related and that environmental protection in developing countries must . . . be viewed as an integral part of the development process and cannot be considered in isolation from it'. It affirms that 'the promotion of economic growth in developing countries is essential to address the problem of environmental degradation', and further reiterates 'the sovereign right [of all States] to exploit their

own resources pursuant to their environmental policy'.

The General Assembly resolution thereupon proceeds to address the current imbalances in global patterns of production and consumption and urges the adoption of a series of measures to help the developing countries to enable them to contribute fully and to improve their capacities in meeting their responsibilities for the protection and enhancement of environment. The suggested steps include:

(1) an efficient and urgent consideration of the developing countries' external indebtedness;
(2) promotion of a supportive economic climate conducive to sustained and environmentally sound development in all countries;
(3) international co-operation in research and development and the utilization of environmentally sound technologies;
(4) identification of ways and means of providing new additional financial resources and special international funds to help the developing countries;
(5) transfer of environmentally sound technologies; and
(6) development of human resources in developing countries for the protection and enhancement of environment.

The resolution thus views environment and development as an integral process. It apportions relative responsibilities. It calls for the mobilization of resources to aid the developing countries to enhance their capabilities to combat poverty and protect the environment. Also suggested are a host of measures to attune, improve, and adopt existing international, regional, and national machineries to the task of protecting and enhancing the environment by sustained economic development.

The resolution chastises the developed world for its profligate production and consumption patterns but adopts persuasive language when it appeals for the establishment of a special fund and transfer of environmentally sound technology. The language employed, especially over the debt burden and servicing the external debts, is non-mandatory in tone and content. The Preparatory Committee is expected to work out strategies and suggest legal and institutional structures for attainment of the objectives laid down in the resolution.

The issues

Momentous decisions have thus to be made by the UNCED on a variety of issues. A number of problems make its task difficult, the foremost of which is the scientific uncertainty surrounding global warming. As seen above, the underlying theory of the greenhouse effect of certain gases (suggested as far back as 1896 by the Swedish chemist Svante Arrhenius) is now accepted.

And, as the IPCC assessment concluded, 'we are certain that increased emissions

of greenhouse gases will result in additional warming of the earth's surface'.[8] There is, however, no consensus on the magnitude of the effect and severity of the impacts. As the editorial in *Nature* of 7 February 1991 stated 'The principle of the connection between the accumulation of greenhouse gases and the prospect of climatic change may be widely accepted, but the detailed consequences of climatic change, and the magnitude of their social consequences, can only be guessed yet. To suggest otherwise, as greenhouse enthusiasts do, is irresponsible'.

Indeed, large areas of uncertainty in today's climate models remain. One such area relates to the impact of clouds. Clouds increase in quantity as temperatures rise, accelerating evaporation from the oceans. But some at high altitude have significant greenhouse effect, trapping the heat radiated from the earth, whereas those that cover about one-third of the oceans have a predominantly cooling effect, reflecting a great deal of sunlight back into space. More research is needed so that the effect of clouds could be incorporated on a realistic basis in the climate models.

The impact studies of global warming have not been able to identify the contribution of the oceans either.

According to one estimate, about 3 billion tonnes is retained, thus reducing the build-up in the atmosphere. Scientists are not sure yet about the optimum absorbing capacity of the oceans and the impact of the increasing CO_2 in the atmosphere on the ocean currents.

These and some other areas of uncertainties raise the perennial problem of the timing of effective preemptive action: should one wait until scientists are in a position to make one hundred per cent accurate statements? The Final Statement of the Second World Climate Conference held in November 1990 and the IPCC have endorsed the prediction that without action to reduce emissions, global warming would reach 2 °C - 5 °C over the next century—a rate of change unprecedented in the past ten thousand years—and that the warming is expected to be accompanied by a sea level rise of 65 cm ± 35 cm by the end of next century. While admitting that some uncertainties in prediction remain, particularly in regard to timing, magnitude, and regional pattern of climate change, the World Climate Conference nonetheless advised that it was 'prudent to exercise, as a precautionary measure, actions to manage the risk of undesirable climate change'.[9] Earlier, a Worldwatch Institute study had stated: 'While it is true that climate change is a young science, many aspects of which are uncertain, there is no excuse for years of delay. If humanity waits until detailed regional climate predictions are possible, it will be too late to avert disaster'.[10]

The issue of equity dominates the discussions on FCCC. It is well known that the industrialized world today emits about 75% of the world's total greenhouse gas emissions, and although the emissions are increasing in the developing countries, where 75% of the world population lives, they emit the balance. The developing

countries argue that although their impact on global climate is minimal, it could be grave. The ceilings and stabilization measures contemplated under the proposed FCCC would entail adoption of alternative energy strategies which would mean for the developing countries diversion of funds from what they rightly consider as their primary goal of achieving rapid economic development in order for them to satisfy the basic needs of their people such as food and shelter. Also, they would be obliged to mount massive research and development programmes which would demand skills, institutions, and human resources many of them do not have.

The Second World Climate Conference noted:

> Developing countries are being asked to participate in the alleviation of the legacy of environmental damage from prior industrialization. If they are to avoid the potentially disastrous course followed by industrialized countries in the past, they need to adopt modern technologies early in the process of development, particularly in regard to energy efficiency. They also must be full partners in the global scientific and technical effort that will be required. It is clear that developing countries must not go through the evolutionary process of previous industrialization but, rather, must 'leap-frog' ahead directly from a status of under-development through to efficient and environmentally benign technologies.[11]

The conference therefore recommended 'a massive and sustained flow of scientific and technological expertise towards the development of the intellectual resources, and the technical and institutional capacity of the developing countries'.[12] It also urged 'preferential and assured access' to technology available in the industrialized world, and additional financial resources aimed at the promotion of efficient use of energy, land-use planning, forest management, soil and water conservation, and strengthening the observational systems as well as scientific and technological capabilities of the developing countries.

Yet another complication that clouds the prospects of the FCCC is the demand by some developing countries for a special treatment of those amongst them which are heavily dependent on fossil fuels for their energy needs. Also insistent is the 37-member caucus group AOSIS—the Alliance of Small Island States—for a special status under the convention.

Equally intractable is the issue relating to the overall regulatory machinery to be included in the follow-up agreements and protocols. Two main approaches are under consideration in the ongoing negotiations: (1) the traditional 'command and control' strategies, which most often entail across-the-board equal percentage reduction in emissions; and (2) 'market or economic' mechanisms, usually implying international tax schemes or systems of tradable or leasable emissions permits. With some exceptions, all environmental agreements have until now been modelled on

the command and control concept, both nationally and internationally. However, the magic of the market place is being pressed into service in the current negotiations. The tradable or leasable emission permits conceived under the market mechanism would mean that all the countries agree through negotiations on a total emission ceiling of, for instance, the emission levels in 1990. The coverage could be all the major greenhouse sources and sinks or it could be confined to energy-related CO_2 emissions. Then an initial re-allocation of entitlements or permits would take place according to the allocation formula agreed upon. This formula can be based upon equal per capita entitlements, or it can use current emissions, GNP (Gross National Product) level, or a combination of any of these approaches as its starting point. Permits might be distributed to the national governments or directly, at a decentralized level, to the industries, with governments serving as co-ordinating units. The permits so distributed could be assigned on the basis of prices and terms set by market standards or through negotiated settlements.

Tradable permit systems have been applied quite successfully as a regulatory tool in the fisheries sector by New Zealand, Iceland, and Canada, and with mixed results in the United States where the system has been used as a complementary device in a predominantly command and control regulatory regime. These sparse and sectoral applications are not exactly ideal examples for emulation in a massive context such as regulating greenhouse gases, a large part of which originates from small disaggregated units—cars, households etc.—where the administrative and political costs of control and verification would be clearly unacceptable. Also almost impossible is the task of the initial allocation of permits. Four different allocation formulae have been advocated so far: (1) the 'grand-fathering' formula, under which permits are distributed according to historical emission levels; (2) allocation based on GNP; (3) by auction to the highest bidder; and (4) on the basis of population. No formula will be universally acceptable to all the countries, but a 'cocktail' of the best features of all may provide a sufficient attraction.

Another regulatory mechanism suggested in this context is a carbon tax, large enough to have substantial impact upon fuel choices, approximately \$ 30 per tonne of carbon. The total revenues of such a tax would be about \$100 billion, or 100 times the current UN budget. Apart from the scramble for a share in these funds and the incentive to manipulate the exchange rate to minimize the payment, the proposed tax is likely to meet with stiff resistance from domestic political and industrial lobbies.

Another difficulty that confronts the negotiators of a global regime to control greenhouse gases relates to the composition of the decision-making bodies. The INC (Intergovernmental Negotiating Committee), at its first session[13] held in Chantilly, Virginia (USA), from 4 to 14 February 1991, elected the Chairman (from France), four Vice-Chairman (from Algeria, Argentina, India, and Romania), the Executive

Secretary (Michael Zammit Cutajar) and the Director. The INC decided to conduct its business through two Working Groups[14] but postponed election of officers to the groups because of lack of consensus among the regional groups on representation. The Alliance of Small Island States sought representation on the proposed Bureau. The vulnerable and developing countries' insistence on representation on the policy-making bodies is obviously dictated by the fact that, under the rules of procedure adopted at this session, decisions will be taken by a simple majority of those present and voting, and access to the special voluntary fund set up by the General Assembly is to be governed by a set of criteria including primarily the vulnerability of countries to the rise in sea level, drought and desertification, severe weather disturbances, etc. The anxiety for a rational share in the special fund is understandable. But the industrialized world does not exactly seem to be thinking in terms of creating a super fund. As of February 1991, contributions to the fund totalled 1.25 million dollars, Japan pledging only 200000 dollars[15].

The lack of enthusiasm on ameliorative action of the industrialized countries is indicative of their scepticism and division over the modalities mooted to meet the challenge of global warming, besides the critical gaps in and uncertainties of scientific knowledge of the degree and extent of the impact of global warming. Interestingly, the controversy over the methods of dealing with the problem is quite acute between the industrialized countries themselves. On how to achieve a reduction in CO_2 emissions, for instance, the European states prefer a programme which will be binding on all the states. The US, on the other hand, is opposed to specific targets for reducing greenhouse gas emissions, arguing that such action would severely hamper economic growth of itself and all countries that rely heavily on fossil fuels for energy supplies. The division amongst the industrialized countries reflects the ground realities of CO_2 emissions.

The World Resources Institute report of 1990-91 points out that in 1987, just five countries contributed 50% of the warming potential added to the atmosphere that year. Three of the top six are industrialized countries, and the other three are developing countries. The top two contributors to the world CO_2 emissions, namely the USA and USSR, accounted for 30% of the world total; and the top three developing countries, namely Brazil, China, and India, contributed nearly 20%. If one were to compute the per capita contributions to the atmosphere's warming potential by apportioning each country's share equally among its citizens, the profile of the top 50 countries will be entirely different. High rates of deforestation elevate Laos and Ivory Coast to the first and eight ranks, and the gas-flaring energy-producing countries, such as Qatar, United Arab Emirates, and Bahrain, will occupy the second, third, and fourth place respectively. India and China do not figure at all in this list; Brazil and US get the seventh and ninth place; and Japan the 42nd.

Between 1950 and 1985, annual global energy consumption and CO_2 emissions more than tripled.[16] Demand for energy is expected to almost double by 2025 and almost quadruple by 2100. Consequently, CO_2 emissions could multiply two to five times during the next century, and the expected heavy reliance upon coal will worsen the situation.[17] The pattern of consumption of energy has undergone a fundamental shift in terms of regional distribution of that consumption. In 1950, OECD (Organization for Economic Co-operation and Development) countries consumed about 75% of all commercial energy supplies; the Soviet Union, China, and their allies consumed 19%; and the developing countries consumed only 6%. By 1985 the OECD was consuming only slightly under half the global energy supplies while the European centrally-planned nations were consuming 22%. Developing countries' share had shot up to 25%. The share of the developing countries is expected to go up to 50% by 2025 and 60% by 2100.[18]

The North-South divisions on issues identified above are going to hinder the progress towards FCCC. Even if some elements, such as financing and transfer of technology, are 'solved' with the characteristic UN quick-fix compromises, the feeling, articulated by Dr Mahathir Mohammad of Malaysia at the G-15 summit at Caracas in November 1991 and earlier in 1990 by the then Environment Minister of India, Mrs Maneka Gandhi, over the CFCs (chlorofluorocarbons) will persist, namely that the South was being called upon to curb its developmental goals so that the North could continue to indulge in its profligate life-styles, and that the North was cheating the South in offering expensive alternative technology as a palliative.[19] Moreover, it is not going to be easy persuading the gas-flaring Arab states to curtail their CO_2 emissions and contribute to the costs of others willing to switch to cleaner technologies. The former Soviet Union's desperate foreign exchange position and the prospects of a warmer climate being actually helpful in growing more food in its frosty north will make it an unenthusiastic negotiator. China is not likely to give up easily its reliance on its immense coal deposits—estimated to be one-third of the world's known coal reserves. The road to Rio is going to be quite tortuous.[20]

The probable normative design

Given the political, technical, and psychological aspects of the problem, the proposed FCCC is likely to take the usual UN form containing the pious enumeration of a series of desirable goals, the attainment of which will be hedged in by the standard escape clauses, such as 'as far as possible', 'in accordance with national developmental policies', not to speak of the ultimate weapon available to the developing countries, i.e. 'national sovereignty over natural resources'. One can expect a renewed debate amongst international law scholars over the normative quality of such an instrument. And as in the case of the environmentally profound World Charter for Nature

(adopted and proclaimed by the UN General Assembly on 28 October 1982 by 111 votes to 1, with 18 abstentions), a liberal section of this world of scholarship will predictably claim for the FCCC the status of an 'overarching principle' of environmental law, if not that of *jus cogens*[21].

The declaration of 'principles' will be probably combined with auxiliary legal and institutional structures for research, assessment of risks, promotion of compliance, dispute settlement, and possibly a mechanism to meet environmental emergencies. One can, with a fair degree of certainty, discount a 'command and control' structure for the future FCCC. Legal prescriptions of that kind will just not suit the climate change problem. And, as Oscar Schachter points out in a recent article: 'It would indeed be fatuous for international lawyers to believe that the general obligation of states to prevent and minimize risks of harm could in itself significantly move the problem of climate change toward solution'.[22]

Endnotes

1. A/RES/44/228 of 22 March 1990.

2. aragraphs A and D identify the following instruments: the Stockholm Declaration, the lan of Action to Combat Desertification, and the Vienna Convention and the Montreal rotocol on the Ozone Layer. For a comprehensive catalogue of the international environmental law instruments, see UNE , *Register of International Treaties and other Agreements in the Field of the Environment*, Nairobi, May 1989.

3. The other major concerns relate to freshwater resources, oceans, land degradation, bio-diversity, bio-technology, toxic wastes, urban slums, and human health.

4. The Conference on Changing Atmosphere held in June 1988 in Toronto, the Noordwijk Declaration on Atmosphere ollution and Change held in November 1989, and many more since then have endorsed the idea of FCCC.

5. Luther J Carter, 'The Global Environment: MIT Study Looks for Danger Signs' *Science*, vol. 169, August 1970, p. 661

6. W W Kellogg, ' rediction of a Global Cooling'. *Nature*, vol. 280, 16 August 1979, p. 615. See also 'Declaration of the World Climate Conference' reprinted in *Environment Policy and Law*, vol. 6, 1980, pp. 103-104.

7. A/RES/43/53, 27 January 1989.
The General Assembly reiterated its concern on climatic change the following year in resolution 44/207 of 22 December 1989, and on 21 December 1990 (45/851) it created the INC (Intergovernmental Negotiating Committee) open to all State Members of the United Nations or of the specialized agencies to consolidate and give a boost to the negotiating process. It also envisaged the establishment of an ad hoc secretariat for the INC and further decided to establish a *special voluntary fund* to finance the participation of the developing countries, in particular the least developed and small island states.

8. John T Houghton (Chairman of the Scientific Assessment Working Group of the IPCC) 1990. 'Assessment of global warming', [Letters to] *The Independent* (London), 6 November 1990, p. 18.

9. *Environmental Conservation*, vol. 18, no. 1 (1991), p. 62.

10. Christopher Flarin. 'Slowing Global Warming: A Worldwide Strategy', *Worldwatch Institute* Paper No. 91, October, p.6.

11. Final Statement of the Second World Climate Conference, *Environmental Conservation*, vol. 18, no. 1, Spring: 1991, p. 65.

12. Ibid., pp. 65-66.

13. For an account of the first session of INC, see *Environmental Policy and Law*, 21 February 1991, pp. 50-53.

14. Working Group 1 is expected to work on emission ceilings, finances, technology transfers and the special needs of the developing countries. Working Group II will consider the legal and institutional mechanisms of the proposed framework convention.

15. See *Environmental Policy and Law*, 21 February 1991, p. 52.

16. EPA (USA), *Policy Options for Stabilizing Global Climate Change* (Draft Report to Congress, February 1989), p. 56.

17. Ibid., p. 56.

18. Ibid., pp. 57-58.

19. See S Sapru, 'Colonialism in environmental garb?' *The Pioneer* (Delhi), 9 January 1992, p. 10.

20. *The Economist*, 7 December 1991, p. 15. Leader, significantly titled 'The hot-air summit'.

21. An IUCN-appointed committee consisting of eminent environmental lawyers so described the World Charter for Nature. See *Environmental Law and Policy*, 13/3/4 (1986), p. 90.

22. Oscar Schachter, 'The Emergence of International Environmental Law', *Journal of International Affairs*, vol. 44, no. 2 (1191), p. 474.

PANEL DISCUSSION

Session 3
Responses

Dr Prodipto Ghosh (Tata Energy Research Institute)

Both Mr Hammond and Mr Srinivasan have stressed that the proposed theme of the convention should be equitable. However, Mr Srinivasan carefully spelt out the Government of India's formulation of an equity principle and said that there should be congruence to equal per capita emissions and responsibility to be determined on the basis of historical and not current emissions. Mr Hammond omitted to do likewise. Since it is unrealistic to expect that there would be an agreement on a convention unless all major parties spell out their positions on such a vital matter, may I request Mr Hammond to spell out the UK Government's position. This is a candid question and I shall be grateful for a candid answer.

Mr Hammond

We are all agreed that the convention must reflect equity but, to be honest, that does not take us to a conclusion of the negotiations: it would be very much a start. From our point of view we regard the necessity of the convention being equitable, in that the different undertakings and different parties making the convention should reflect the different circumstances and the situations in which they find themselves. Broadly speaking, the convention is looking at the commitments and undertakings which would be different between developed and developing countries as is quite right. There are other groups within the negotiation such as the East European countries—countries with economies in transition—who would also like to see some differentiation of treatment to reflect their circumstances. Others have raised the issues of the island states and countries particularly vulnerable to the impacts of climate change. They too would wish to see that particular situation to be reflected. Broadly speaking, I think the convention will certainly be able to reflect the different circumstances of developed, developing, and least developed countries. Those are three differentiations which have had some precedent. We have the UN definition

of the least developed that would be possible for us to adopt in the convention. So I think one could look to a convention in which the undertaking countries take on themselves, reflect those three divisions and, I should emphasize that the way we see the convention as a whole emerging, it would be very much built around national planned programme strategies. So that each country would have the full opportunity to take account of its own national circumstances in defining and reporting the actions it is undertaking under the convention. So to that extent we would see equity reflected very fully in the structure of the convention.

Mr L T Gehani (Rivoin Floors Ltd, Hyderabad)

We have been discussing over the last two days about the atmosphere and the land surface. It so happens that in the advancement of science the after effects are known much later e.g. CFCs, pesticides, fertilizers, plastics, and synthetic fibres; some of these are not biodegradable, and we face the problems much later. The immediate effect, of course is, the alleviation of poverty or disease. I think you have not touched upon one subject. We are looking for better geothermal energy. We are boring into the bowels of the earth to search for oil. We are looking for minerals and food from the sea. There should be some kind of thinking on what will be the long-term effect of these searches. Nature has its own way of balancing things. Earth, as a part of nature, is a symbiotic system and nature has taken care of this long ago. We must have some advanced thinking on all these things. What is the effect of boring too deep into the bowels of the earth? We have tunnels for transportation - we are now boring into the bowels of the earth in our search for oil and things like that. There should be a thought that we must learn to live naturally and help nature in not creating adverse effects of this scientific progress. This might apply to biotechnology, it might apply to geothermal energy etc.

Professor Menon

What you are really saying is that one should try to assess wherever major actions are taken, where there is human perturbation on the environment - to see whether the environment can take it. That ought to be generalized like an environmental impact assessment. If you wish to put a factory down and you discharge effluents and then you just see whether the water systems can take it. How soon will they clean up? And if they can't, you are forced to clean it up yourself at the beginning before you let it out. So it is general statement you have made on that, but not directly related to the issues of climate change or global change or UNCED as we are currently discussing.

Mr B G Verghese

Taking up from what Anil Agarwal said this morning about population and consumption, would it be useful (if it has not been already done) to create some

kind of a concept of ecological man, and use that as a yardstick for measuring all the kinds of changes that need to be made between North and South. I think one of the speakers earlier, perhaps it was Mr Sandbrook, talked about ODA now being less than the net transfers being made because of debt to the developing world from the Third World. That obviously needs to be corrected. One way of doing that would be to seek to transfer these debts to some multi-lateral institution rather than just an existing one like the World Bank, and to use that to enable the developing world to make a demographic and development transition. That I think is a vital input in dealing with the long-term effects of population on resources and global warming. The third point is that when we talk about the transition from existing levels of emission or whatever or resource use systems, we can't have the same amount of time allocation. I think there has to be a larger allocation of time for the developing world to make the transition and to some extent within this period things may get a little worse before they improve. And that has to be built into the system rather than have fixed deadlines—if you don't conform by this period the following happens. These points are summed up in the Gandhian phrase that there is enough for everyone's need, but not enough for everybody's greed.

Dr P K Das (Department of Ocean Development)

A common refrain in all the presentations has been the uncertainty of different scientific projections. In that context, I would like to offer a suggestion which concerns the setting up of certain research centres which would supervise or at least encourage quality control,exchange of data, standardized methods of measurement and in general try to assist in greater quantification of the uncertainties that are prevalent. We had such a centre set up during the Monsoon Experiment in India and elsewhere, and it might be a good precedence to follow.

Professor Menon

Yes, the concept of these Regional Research Centres which has been now discussed and is likely to fructify over time would include some of these features.

Dr Sukumar Devotta (National Chemical Laboratory)

I just want to address a question which has not been discussed particularly. With my experience on Montreal Protocol, I found when there is a negotiation going on for technology transfer, what is not addressed is the future technology independence. What I mean is there is no money available for R & D; even on multilateral fund, R & D is not included. Technology adaptation is included but not research and development. What I mean by that is if there is a substitute available the North will transfer the substitute technology to the South but only for the adaptation cost is included. Technology transfer fee is included, adaptation is

included. If you want to have any research and development there is no money included.

Dr Sinha (University of Calcutta)

The various presentations this morning. It show that the NGOs have taken a distinct stand, but I am not sure what kind of stand has been taken by the scientists per se in that convention on climatic change. Perhaps some light might be thrown by Dr Joe Farman—he is at least one of the scientists who did strike some kind of discordance, apparently to me. So what kind of stand was taken by the scientists at that convention? There should not be an impression that it was something feeble and the NGOs and other people, particularly Mr Sandbrook and Dr Anil Agarwal have taken a very distinct stand.

Dr Joe Farman

I feel very flattered by that, because I don't consider myself particularly competent in the field of climate change. I still insist that the ozone problem is an acute problem and the climate change problem is a chronic problem. Luckily for the acute problem there is, I feel, a cost effective way of doing it; in fact when you look at CFCs, they turn out to be rather expensive, they taught you a lot of wasteful habits and the world would be rather better off mostly without them. There are a few medical uses that we can accept. Equally one has to be a bit careful, I think, about the halons, because halons in certain situations, for example, in the cockpit of an aircraft where it may or may not save the pilot's life and by implication the life of everyone on board the aircraft. Now there is a place for these in the world. What we have to learn is that we only use them where they are necessary and don't go about wasting them. But climate change is much more difficult. At the moment, I think Dr Pearce put it right, we are paying an insurance policy in order to give us time to understand and to perhaps get rid of some of the scientific uncertainties. The bottom line which I like to use when I am called upon to make these sort of statements is quite simple. We have got to the stage where we are changing things faster than we understand and at best that's simply imprudent. It is only prudent to do things slower and to be more cost effective in what we do and so on. Its certainly not the scientist's job to ask you to change your lifestyles. I don't think we will get anywhere if I ask you people to make sacrifices. We have got to do things in the way in which we show the ordinary person will benefit from it. There can be no question of interfering with India's agriculture—of course you've got to grow rice. If it creates methane, well, hard luck. We've got to find some way of compensating for that amount of growth in methane by some other means. We are all human beings. We are in this together. Let's try and do it in the best possible way.

Professor Menon

The questions of ozone and capital costs were indicated and references were made to the London Discussions where Mrs Menaka Gandhi was there and I think Daryl D'Monte had referred to it. The numbers were pointed out. I am given to understand that in the United States the total cost is going to be around $ 250 billion. I don't know whether this is correct; this is a figure from Du Ponts themselves in a talk, which I had noted, by their Vice-Chairman in charge of this area. It is very clear that if you are talking of $ 250 million for the whole of the Third World, this will take us nowhere, and what it will amount to is it will not get through.

Dr Joe Farman

The important thing with CFCs and with halons is that they should not be released provided you recycle these things. Take Germany as a case. Germany is going to phase out the production of CFCs, they have said by 1995. That does'nt mean that by the year 2010 you won't be able to go to Germany and find a refrigerator without a CFC in it. In actual fact there is no need for any intensive capital costs at all. We can run these things sine die; we can make full use of the capital already invested; and the great point is we do not need substitutes, we can do things perfectly well with already known technology. We can blow better foam now, with the same equipment as was used for foam blowing of CFCs with carbon dioxide and get better foam from it. We simply don't need the immense amount of cleaning agents which are thrown away. Aerosols are a waste of everyone's time and money, and so it goes on. For example, the European Community for HCFCs want a 300 kilotonne production. This is absolute nonsense. By a 10 kilotonne you can change every refrigerator in Europe within five years. If you allow people to set up these massive plants you are simply encouraging to get their salesmen to find new uses, and in particular throw-away use so that they can sell you some more. All these vast figures I think are over-inflated.

Professor Menon

So the main point then is that one has to have a totally new approach which is not what is being defined at all today by either the EPA or by industry. Now one has to look at the new parts where we can see about concern.

Member of the Audience

Just reiterating your point, the current figure is about 240 million dollars for the multilateral fund. But I heard just Malaysia alone has put up a proposal for 240 million. So that is the kind of money we are talking about.

Professor Menon

No, that is exactly the reason why I brought this rather large sum as given by Du Pont themselves. Of course, they are interested in it because there is money in it. But I mean the point that Joe Farman is really making is one has to take a different approach to the problem. And the question is, has that been worked out by anybody?

Dr John Vallamattam (Editor, *Indian Cement*)

I am a layman in the field of climate change and ecology. I have what might be a foolish question. I have been taught that the thousands of years in which the world has been transforming itself and has come to the particular stage we are in. Now these three days of discussion we never mentioned the natural transformation and perhaps the natural correctives that have been taking place in the world. We have been analysing as if everything was man's creation and man's mischief as it were. Should we also take everything that seriously?

Member of the Audience

I wonder if I could ask for the Government of UK position on the so-called joint implementation proposal that came up at the last INC session which was proposed by the Governments of Norway and Germany. In essence the joint implementation proposal is intended to allow the developed countries to meet a part of their reduction commitments by paying for reductions to be made or sinks to be enhanced in some other countries. What is the Government of UK position on this?

Dr Joe Farman

Yes, the UK and the European Community made a statement on the Norwegian proposals at one of the INC sessions that they have repeated since. The Community made three essential points about the Norwegian proposals. We very much welcome the proposals. We think there is lot of merit in pursuing them. But then we had three particular concerns at this stage. First, it should be clear that these arrangements should be applicable beyond the initial commitment that we expect developed countries to take on in the convention. That is to say they should not be part of the process by which we meet our initial stabilization target. That target can be met by us domestically, and it should be met domestically. Secondly, that when these arrangements come into effect - if they do - they should be between countries that both have commitments under the convention. Thirdly, that in no way should any such arrangements reduce the environmental impact of the convention as a whole. On this third point, perhaps to elaborate on it for a moment, what we mean is that in taking measures outside one's own country for which credit would be attributed to one's own target, one should not fund or pursue or support measures which might otherwise be taken in any case. That is to say that the total effort we

make should achieve the maximum reduction in emissions worldwide. The Community, I think, stands by that decision that was put forward in the past. I think, from the UK side particularly, we see a lot of interest in pursuing these ideas, but we also see a fairly substantive negotiation to bring them into place, and we would not want that to detract from the initial agreement of the convention by June.

Professor Menon

I have with me three questions which I am going to read out and get the answers from the panelists and then we will continue.

Question to Dr Anil Agarwal: From your talk would you like to deduce that the environmental issues of today that are likely to be prioritized are contrary to human rights issues? IPCC Report has confined itself to scientific excellence but surely its relevance is to both the environmental issues and to human rights, irrespective of various divides, and therefore remains the basis for solving both.

Dr Anil Agarwal

First of all, I would say that the issues that we have before UNCED per se are not against human rights. The important thing is how do we try and solve them. The management systems may be such that they may not give respect to equal human rights. And to me, when I look at the global warming problem, and the kind of management systems that are being proposed, my problem is with that. It is not with the problem as such. The issue is the nature of the management systems that we try and develop should be such that it gives equal rights to all human beings. Another important aspect of this is that the kind of management systems that we are trying to develop are built largely around international laws, i.e. conventions like the ones that we have had in the past for ozone or for toxic waste; and now that we are proposing for global warming, bio-diversity and so on. In addition, there are a number of other efforts being made to green aid, to green trade, to green debt, and all those kind of things. Now all this as I was saying in the morning leads essentially to levers of power that exist in the North. It does not give any corresponding levers of power to the South and that approach to my mind is against human rights. Because if we are talking about global environmental management and if we are accepting the basic principle that what happens in the North is likely to affect the South, and what happens in the South is likely to affect the North, then any management system must then give equal intervention rights to all people. That definitely is not on the cards in UNCED. Nobody is talking about that. So it is more in terms of how we try and solve the problems, that the human rights question comes in. In fact, at our Centre we are developing a series of concepts of how we can deal with the environmental management problem from the human rights point of view. Looking at human rights at the level of a community and its

environment, looking at the human rights at the level of a nation and how its people can intervene in the management of a nation's environment and as well at the global levels so that these global problems are more amenable in terms of more global democracy where each one has an equal right to be able to intervene and bring about certain checks and balances.

Professor Menon

A question for Mark Tully. Your talk today seems to suggest that the media, electronic rather than print, will pick up environment issues only if (a) they are at the disaster level or are sensational, (b) if politicians discuss them or (c) if they are made controversial. How do environmentalists make themselves newsy without being irresponsible or sensationalist?

Mr Mark Tully

That's a very good question to which I find it very difficult to put an answer. I would go back to my original definition of the difference between what I call news and documentaries in environmental terms. I do not think that the electronic media has been that backward in their documentary coverage, and I said we are working very hard now on this one world concept before we come to the United Nations Conference. But I do think that in news terms which is what seems to have the biggest impact there is a very real problem here. The three categories which have been defined are very very true indeed. Those are the categories which tend to hit the news. What might appear to be gimmicks are in fact effective, and it may not be very wise of people like Greenpeace to play down that type of tactic. I honestly do not think there is an easy answer to this question in news terms. I would also just add one thing that obviously I would repeat my earlier warning that if people are going to go in for gimmicks then the gimmicks must have a sound story behind them. There must be a real problem to which the gimmick is trying to address people's attention. I have always said in public, including within the BBC, that I think we journalists have to think very hard about what we call news values. I don't think we have addressed the problem of news values adequately yet and I would hope that maybe the environment might be an issue which would persuade us to address those values.

Professor Rahmatullah Khan

I agree to the comments.

Dr Ibrahim (Indira Gandhi National Open University)

Having listened to all the distinguished speakers here I have a feeling that the words of Ellen Wagner in *Peace With the Earth*, fit in very well. She has said: 'Against the ideals of the day, mechanization, specialization and speed, we consciously put up

what we think will be the ideals tomorrow: self-activity, diversity, and patience'. We can adapt her quote to fit three levels of our activity: first, the micro level, which involves the family unit; secondly, the meso level or the intervening body of scientists who help shape our social advancement; and third, at the macro level, the giant corporate and other analogous structures that constitute social forces that affect decision making. These three are very important for the micro, meso and macro level handling of climate change. At the micro level, this is addressed to all of us, there has been a very important shift from mechanization to self activity. Take for example our obsession with freshners of every kind when these are in fact nothing but aerosol poisons that are polluting the very earth, and the cumulative effect of all such lifestyles is now taking its toll in the shape of the threat of climate change. At the meso level, I would address to Dr Sandbrook, specially where he has talked about environment and development, we have to meet the challenge of specialization, because this division of the world around us has proved to be a major hurdle in our perception of the wholistic view of our planet and this attitudinal aberatyion has to be met with a gradual but firm opening up to the diversity that is crucial to any understanding of existence itself. Thirdly, at the macro level there has to be the necessary control on the urge to reap short-term benefits out of major enterprises. The speed at which we want profits has to be replaced by patience with which we have to learn to wait to benefits which are more enduring.

Dr Hiden

I am from Stockholm, Sweden. I am a power engineer and I am very much interested in electronic networking. But today I would like to ask the speakers for a comment on one thing which I think is rather fundamental. The morning session has concerned itself with human resource management really. We have heard about business, politicians, public and about the NGOs. But I have'nt so far heard anything much about the military sector. Of course, we all realize that the military have often a negative impact on the environment. You only have to travel around in Eastern Europe and see where there have been air fields, for instance, and look around them; or rather look at the military installations - look at Kuwait - and look at what military activities can do. But we focus too much, on the negative aspect of military activities. I would suggest that there is a tremendous potential here which is under-utilized. It is the potential of re-deployment of the capacity for systems analysis and for getting things done. Unfortunately, of course the military have solved their own problems with the wrong means, normally. But there should also be a possibility to make use of their capacity to make specifications and to get industry active to meet those specifications. I think that many countries of course now face re-deployment of very large numbers of people who are trained at doing what they are told. I think it would be a pity if one missed the opportunity to guide at least those cadres of the

engineers and so on in this establishment that can be directed towards environmentalist's use.

Mr Sandbrook

If I understand this question correctly about shifts in attitudes at what was called the meso level, I think I essentially agree with the point. There is an enemy as it were of progress on environmental thinking which is the sort of specialization that goes on in so much of human thought and activity. In the sense we are all trained, certainly we scientists have been trained in reductions thinking, and many of the problems which we face in the environmental development are not really suited to reductions thinking. They are cross-cutting issues, and they are inter-disciplinary issues, and I make a distinction here between inter-disciplinary and multi-disciplinary: a university is a multi-disciplinary organisation which has lots of different departments and they really don't talk to each other. An inter-disciplinary organization is one where the different departments do talk to each other, and I would just sort of say a word of optimism here. I think some of the most exciting things happening academically are the way these disciplines are mixed up. Environmental economics would be one area. I think environmental economics is alive and well and is probably more alive and more well than many other branches of economics. Another example is the mixture of ecologists with agricultural science where you are looking for sustainable agricultural systems is another area where the old discipline boundaries are being broken down. Now, of course, pulling all of this together where you go up the frame to governmental structures, where you have departments of transport, departments of environment, departments of defence, etc., and getting those to interact so that there is what the Brooklyn Report called an environmental reflex throughout government is a very difficult thing for governments to organize and we are only really learning - all of us have to do it. So I generally agree with the point as I think I have understood it.

Dr Pearce

The question was that profits needed to be replaced by patience, and I do so agree with that. If I translate that back into economists language then I think that means I have to try and find ways of integrating sustainability into everyday government decision, business decisions and also for that matter household decisions. Now I think we have made quite big advances for example in redesigning the way we look at investments in projects, e.g. making sure that environmental costs are taken on board, in the way that we measure economic progress, and so on. All of that is a very active area throughout the world now and I think has reflected the influence of the sustainable development school of thought. It boils down really I think to saying that we have to start designing our economy with nature in mind. But if

I can finish with a general comment: I think all of these fairly general reflective views are interesting but they won't change the world, and I have a great worry that this conference has gone off into discussions of morality which are fascinating, interesting, important, but all revolutions take time, and I am afraid I don't think we have that much time.

Dr Jagdish Bahadur (Department of Science and Technology)

I would like to draw the attention of the house to the extreme environments created by weather, i.e. deserts and glaciers. You know we often hear about droughts, glaciers, ice ages and sea level, and paleo-environmental and climatic record resurrected from the ice core study. These two extreme environments are inhospitable to a common man but not to a naturalist. One-third of the earth's surface is occupied by deserts and glaciers. They are very sensitive indicators of climate and its change. Very little monitoring exist on our earth. On glaciers everybody knows that it is snow which rules supreme, and on deserts sand rules supreme. And their environment does not like its change. But there have been oscillations in the coverage of these two great extreme environments. One has found that even the deserts, given the water and other resources, could be most productive. And one has also made a study that when there is a warming of a drought year glaciers give you more water than during a flood year. So we should do much more to this one-third environment on our earth's surface.

Ms Neha Khanna (Tata Energy Research Institute)

My question is jointly addressed to Dr Pearce and Mr Sandbrook. During the course of the day different speakers have mentioned that they were setting up a fund to meet incremental costs of strategies to developing countries. The question is (a) how do you define this incremental cost, and (b) how do they relate to the site payments mentioned by Dr Pearce? One would imagine that if the site payments are to be used with an incentive for the developing countries to sign on then they should be somewhat greater than the incremental costs.

Dr Pearce

I think that is an enormous question at this stage of the conference to actually define how incremental costs should be measured. I think there is another way round this, really, and that is to look at what it will cost the world to meet some kind of predetermined target. And to ask a question: What's the least expensive way of meeting that target? And to do that you then need to look at the relevant costs in each different country, and one of the results you may come up with is that it isn't necessary for each and every country to make reductions in CO_2 but for the initial burden to fall on those countries who find it cheapest to actually reduce CO_2.

Now what that then implies is a set of transfers because in some circumstances those costs will be more than worthwhile for the individual country to bear, because they will get domestic benefits from doing so. But inevitably there would be a tranche left over which that country cannot afford, or where the domestic benefits don't justify that kind of activity. And that then determines the size of the transfers that you need. Now I have no idea where those transfers end up. It may be quite surprising - you may wish to give them all to the Soviet Union, as was, or you may find they all come to India, or you may find they all come to Europe. It is a matter of empirical evidence. But I think that is a somewhat different way of going about the issue and I would suggest perhaps a slightly more efficient way than setting each country a target and then saying what incremental cost is that country got to bear, and then determining the transfers from that. I would argue that that's wholly rather an inefficient way of going about the problem.

Mr Sandbrook

I have great difficulty with the definition of incremental cost in respect of climate mitigation. One of the reasons why I argue putting the two agendas, the sustainable agenda, development agenda in Agenda 21 together with the planet fund is at the end of the day I think that the least costs solution to the climate change problem will essentially fall to four or five economies - China, India, Brazil and perhaps a few more, which will leave the rest of the UN family with absolutely nothing. And that's why I want the sustainable development agenda put alongside so that we don't fall into the position where the newly industrialized economies get what is seen to be a dividend out of the issue, and nobody else does. Now, when it comes to defining who gets what, it seems to me that the whole basis of this should be the national plans for sustainable development which includes climate mitigation issues, and there you should look quite clearly at what can be met by internally generated resources and what will need to be met by external or additional resources from the North. But to answer the question in the absence of a sustainable development package and a plan by nations state, is very difficult.

Dr H S Rao (National Institute of Science, Technology and Development Studies)

One point which has not so far been brought out in this seminar is the potential of hydrogen as a fuel and possibilities of human neglect. We are not really that far away from this context because reactions have known in photochemistry that you can use solar radiation for converting water into hydrogen and oxygen, and yesterday during one of the discussions the cost of discharging one tonne of carbon products into the atmosphere to the society was estimated at US$10. Now I would like to suggest that at least a part of the set of tax or cost whichever way it is computed we set apart for actual research on hydrogen as the ultimate answer to the problem of the greenhouse effect.

Professor Menon

It is well known, and if you wish to you can write to Lord Porter, past-President of the Royal Society who is at Imperial College, who has done a great deal of work relating to the question of getting hydrogen, that it is not very simple to lay water on somewhere and get photoeffects from the sun and break it up into hydrogen and oxygen. There is a great deal of work on other chemical compounds, complex organic compounds and so on which can be laid out, but there is nothing successful yet which delivers you positive energy systems.

Mr Prabhat Gupta (National Physical Laboratory)

A lot has been said about the greenhouse gas emissions from the developing countries and its implications to climate change. We very well know that most of the developing countries are in the tropical belt and which have highest OH concentrations and also which leads to methane emissions, methane sinks. There is a lot of forest cover which an fix the carbon dioxide. So my question is: are we going to take greenhouse gas sink potential also in the conference which is going to be held in Brazil.

Dr Mitra

The first comment about the sink is that not all of it been very well understood. The second comment is OH is indeed a very important parameter because it determines the lifetime of many of the greenhouse gases. The third comment in regard to the OH loss of methane being more in the tropical regions, that is correct. In fact if you limit yourself to not just one country but a region defined by 30 degrees north and south—a fairly large chunk of the world—then you find that the total amount of loss of methane is in fact more than the total source. So there is a net loss, rather a net sink, rather than a net source. The fourth comment is often one finds that an arid area or a non-water logged area there is an uptake of some of these gases. Their total cushion of water, the carbon dioxide sink in the ocean is still also not understood. So sink is an important parameter. Sometimes sink, if the calculation can be done well, as in the case of methane or better as in the case of methane, then you use that as an idea of what the total budget is likely to be.

Dr Jenkins

I would fully support those comments from Dr Mitra. I think the problem is that we do not understand these sinks well. For example, there may be a very large sink of carbon dioxide in North Atlantic. But these are all natural sinks. I guess what we have to do is make sure that we protect existing sinks so we do not credit people with sinks that have existed for many thousands, millions of years. But we must

seek to protect the sinks that are already in existence and stop them being minimized.

Ms Amrita Achanta (Tata Energy Research Institute)
Rice fields are the sites of both methane emissions and nitrous oxide emission. I wanted to know whether there is any interaction whatsoever between these two emissions?

Dr Mitra
Not directly. You were talking about the N_2O and methane. But when methane is oxidized, the products of that can interact. That's not a very major one. The main problem is really the OH radical. But OH radical is produced essentially by forcing the delta. That atomic action must come from ozone. That ozone must be in the troposphere. That tropospheric ozone is not sufficiently large to produce the delta. Therefore it must come from the stratosphere. So the key parameter is really the stratosphere. Flow of the stratospheric ozone to the troposphere through the tropopause. And one must realize that in the tropical countries the tropopause is much higher—16 to 18 km than in the mid-latitudes—6 to 8 km. That's one of the major key parameters in this system.

Dr Hiden
Just one word with regard to sinks. Of course it is important that one looks at the existing sinks, but also of course, one should consider normal types of sinks. For instance a calculation has been made by Professor Carl Hodges of the Environmental Research Laboratory, Arizona, who is working on halophytes. There is this halophyte by name of *saloconia* which is an oilseed. The calculations indicate that if Saudia Arabia would make use of all its potential for cultivating *saloconia* one should be able to balance the export of oil. This is of course a theoretical challenge, but I think halophytes—plants that grow even when irrigated with sea water—have a potential one should not overlook.

Dr Mitra
Since at one stage the emissions from the Gulf War was mentioned, I would like to state what the amount is. The estimate now of the carbon dioxide emission from the total system from the Gulf War is 65 megatonnes, which is 1% of the annual emission.

Member of the Audience
Dr Pearce stated that industrialized countries have a self-interest in inducing developing countries to participate in a climate change convention and out of this self-interest they would be induced to transfer funds and/or technologies as side

payments or incentives. I would like to be quite clear as to where exactly the self-interest of the industrialized countries lie? Is Dr Pearce's position that without the participation of the developing countries the abatement efforts by the industrialized countries will be nullified? In that case, one implication would seem to be that developing countries do not perceive the prospect of actual climate change in the future as relating to their own self-interest and that only industrialized countries do so. On the other hand, does the self-interest possibly lie in realizing the prospect of creating benign technologies and plant and equipment embodying these technologies? In that case the financial transfers that we are talking about would be really no more than commercial credits and no incentives are implied.

Dr Pearce
No, it is the former. I did not make any assumption whatsoever about any benefits to the North from the transfer of technology to the South. Assume if you like that the technology magically appears in the South, it still remains the case that the North has a self-interest in bringing the South on board. It simply reflects the fact that if you look at rates of growth of CO_2 emissions, by means of a fairly simple model, let's say a model reflecting the IPCC estimates, then an agreement between all OECD countries leaving out the entire developing world really does not do a great deal that's terribly dramatic to rates of growth of warming. If you have got a long-time horizon, the rate of growth of CO_2 emissions in the developing world will quickly nullify that agreement. So my point was simply that there is a bargaining counter which the South can take advantage of. The issue really is, how do you take advantage of it. There I think the debate seems today to boil down to whether one takes the moral high-ground, which I don't dispute exists at all, or whether one attempts to use this more strategic bargaining approach which I think in fact is the approach being taken by your negotiators.

Ms Suman Khanna (Environment Study and Research Group)
As a person who is interested in peace education I was just wondering whether the IPCC has on its agenda a programme by which it can reach lay people or the general public via publications or other means with all its valuable findings. I know Greenpeace has such packages, but does the IPCC have some?

Dr Jim Skea/Dr Jenkins
The IPCC response strategies working group did specifically mention the question of public education as being an absolutely crucial part of the response to climate change. I think its part of the agreement: you would find that the responsibility for actually implementing these measures is that of the national governments and the NGOs within the countries concerned. I would say on the education side that

there are a number of steps going on in the UK and the standard curriculum for schools, for example, includes a considerable component on environmental issues now. It is certainly a part of the training for teachers as well, and these official activities have been supplemented by the NGOs of course. Friends of the Earth is producing school packs which are available for schools doing particular projects, and for all these reasons I think you tend to find that the most educated age group among the population is probably the 8-15-year olds.

Professor Menon

I just wanted to make two or three quick comments or points, not an elaborate statement. First, with regard to the question raised by Dr Jagdish Bahadur I wanted to mention that under the International Geosphere Biosphere Programme several of the questions raised with regard to all the arid zones, deserts on the one hand, and glaciers on the other will be covered. I can give you a list of places, for example in West Africa the region north of Chad and Mali, the Sahara, in East Africa the South Turkana ecosystem, the Upshonore Pilot Project in the North Gobi Desert (between China, the USSR and Mongolia), Australian pilot project . . . a whole range of these things are being done which relate to land-use changes and the whole hydrological cycle. So it is not as though that's not been dealt with, it will be covered. Secondly, we have dealt with many questions of climate change and so on. Dr Anil Agarwal mentioned this morning the two sides of the coin. One being population, and the other being the affluent levels leading to high consumption in the North. Now he is very clear that the population, which is already at 5.3 billion, is going to go to a level no less than 8.5 billion. There is no question about avoiding that. It is likely to go to figures higher than that and it depends on the ranges and the assumptions you make which will take you anything to 10 or 11 or even up to 15 billion. If you look at the countries that have 50 million and more today—India and China lead in this group—you will find that all the big countries have very high figures for total replacement fertilities. India has 4.3, whereas 2.1 is the rate required for stabilization. Pakistan has 6.5 with a population of 122 million, Bangladesh 5.5 with a population of 115 million, and Nigeria 6.9 with a population of 108 million. I, therefore, do not see any stabilization taking place at these figures. One should therefore assume that we will get to something like 10 or 11 billion. This can only be dealt with if there is development and poverty removal. I think this is absolutely fundamental; it has to be recognized. Otherwise we will be dealing with a much much larger population and much larger needs of the population, including energy. Dr Pachauri had projected some figures on energy which took us from around 10 terawatt to projected figures in this century of about 13 or 14 but ultimately saturating around anywhere between 22 to 26 terawatts. This depends on the assumptions you make. Therefore you are going to have a factor of 2.5 to

3 times the current energy consumption and there is really very little escape from it. There is a limit to the hydel potential and in terms of terawatts, whereas renewable energies and so on will certainly meet very large requirements for decentralized local purposes. But if you are really talking of terawatts required for large industrial purposes then it has to come from bulk power generation. Bulk power generation today essentially means fossil fuels unless one goes the nuclear route and you can see the problems of the environment that come out of the nuclear area. Therefore, we will have to live with it, and therefore one must on some basis also plan for strategies that will enable us to deal with the situation as it stands rather than just say we will go back to some hypothetical situation. Third, when we are talking of all these warming and temperature changes the figures essentially relate to global surface average figures whereas what is extremely important is to be able to finally define what it will look like in different places in different regions of the world. It is not only the global picture but the regional pictures have become extremely important. In this connection we must essentially support very strongly the importance of doing much more work. One has to see to this point on the basis of individual scientists and individual scientific programmes. If you see what is the carbon dioxide measurement on which all of this discussion has been based—it is not a large, co-operative international programme of any description. It is not a programme like Man on The Moon or anything similar. It has been done by scientists working over long time periods, individual stations and these things have come to our notice. And that is why one has these big programmes now which are co-ordinated programmes of which the bulk costs are purely on satellites and ships; other than that the scientific part of it is relatively small. We need to do much more science if you are going to understand the earth with its large population, with its needs and are able to meet them. Even if there is a highly co-operative society based on human solidarity and understanding and everything else, we will need food, we will need water, we will need to grow that food, energy will be required for heating, for cooking, for a variety of purposes—you just put that down and we will therefore need to understand how to live with this large and growing population until one has secured that level of development. Therefore it is important to do much more science on both what is the nature of the earth's environment and how it responds. If we are getting to the stage when some of these things will happen, we need to know how to deal with it in terms of the rest of science that goes with it i.e. the response side. I think both these are equally important.

Dr Anil Agarwal

I wanted to come back to that question, namely about if the North tries to reduce and the developing countries don't try to reduce the effects get nullified. Particularly keeping in mind what Daryl D'Monte said this morning, these kind of questions

are very mathematical in nature, and have a number of assumptions built into them. It is very important that these issues get thrashed out because it is very easy to pick this up, and this becomes a very emotional argument that regardless of what we do, the people out there are not co-operating. I am not sure of the figures that Professor Pearce is quoting, but I have seen some very different figures prepared by Kirk Smith, where he looks at current emissions growth rates of United States and of India and he assumes India will have the same rate of growth in its emissions as of now and even with the United States stabilizing its emissions growth rates in the next 20 or 30 years, India does not contribute to the stock of carbon dioxide more than 5 or 10% of what United States will. He has similarly compared Switzerland and Bangladesh, and the figures are very different. So I am not sure which studies we are talking about, but theoretically speaking this kind of figures would be based on a lot of assumptions. If you were to assume that the industrialized countries would reduce by say 20% over their current emissions then it is quite possible that in the next 30 years we might make up for that 20%. But the question to my mind is why 20%? If what Richard Sandbrook said that the environmental problem is one of equitable property rights in some of the common property resources, and if all of us have equitable property rights in the atmosphere, then the industrialized countries cannot reduce by 20%: they have to reduce more like 60 to 80%. And if they do that I cannot see any growth scenario in the developing world which is going to swamp that effort of the industrialized countries. So it is a very important question. What are we trying to achieve? It is only when we answer that question that this particular point can be made. Whether the efforts in the North will be swamped by the efforts in the South. This is an intensely mathematical question and one can juggle around with this mathematics, but those kind of statements can be intensely emotional. This is precisely the kind of thing that I would see BBC displaying on its news items, saying regardless of how many carbon taxes we put out and everything we do those people out in the South are going to swamp our efforts etc. So unless I see the figures and I see the assumptions beyond the figures, I cannot accept that statement.

One of the British speakers

Well, its late in the day to debate this, but just to make the obvious point that if this was not true, why is anybody bothering to try and persuade the South to join a convention at all? We would'nt need them.

Dr Anil Agarwal

We are trying to do precisely that because it will deal with a heavy cost on the industries in the North. And if the industries in the North are going to bear that

burden, they are going to become uncompetitive. One of the prime reasons, to my understanding, of the American position is that the Americans are already very high on emissions costs. That is why if at all they would like to have a global warming convention, it is to make sure that everyone gets on to the ball game.

Professor Menon

I also think that we have to look at practicalities and one of the questions that is going to arise is whatever anyone does, whether the North is going to come down by 50 or 80%. I have raised this point earlier that one should also see how one can live with the situation and what is it that we know about climate change in terms of its details. I mean, we certainly know there is a warming, there is a question of this average temperature and so on but I think we need to understand much more of its implications before one gets into enormous dimensions of societal change. There are many things we ought to do which are prudent to do, and which need to be done. But there are other things which one has to see on the basis of more understanding.

Mr Sandbrook

I was just going to reinforce that point because many of the strategies designed to cope with change are in fact going to be very supportive in a mitigating sense. The two are very synergistic. Basically everything you do to—with or without climate change—to move to a higher level of sustainability within an economy is basically good news for the climate picture.

Mr Verghese

Apart from things like afforestation, which augment the sinks, are there any artificial means of augmenting sinks? Could that be if not an alternative—an equal line of approach?

Professor Menon

In Japan they have set up an institute called RITE which is headed by Professor Zero Kondo, the President of their Science Council. They are dealing with all forms of carbon fixation—biological, chemical, physical—a whole range of it with pilot plant experiments and he gave a whole lecture the other day when I was in Tokyo. There are research programmes of this nature. Now, how successful they will be, how cost competitive they will be, whether they will be worthwhile in a context of the type of change taking place, I don't know. But there is an effort going on in that direction.

Mr Phillipe Dach (Indo-French Programme on Solar Energy).

It sounds a little naive but could have important policy implications. It comes from an apparent contradiction I perceived in Anil Agarwal and Ashok Khosla's argument regarding the impact on environmental changes to the rich and to the poor respectively. Should we argue that the ones who will lose more are the ones who have something at stake? That means the more affluent or the most deprived ones, like Anil Agarwal was saying. I believe from my little personal experience that the gravity of the situation is the keyword here, i.e. the affluent people will probably be able to afford the means to correct whatever impact might come out of global warming. Whereas for the others the line is very thin between a situation in which you just manage to survive and the situation where you just cannot survive anymore. So the types of measures taken will obviously not be sustained to ensure development of the most deprived, be it in industrialized countries or in developing countries, or to protect the level of comfort that has been achieved in industrialized countries and also in developing countries. So I am wondering if we should draw a line between the interests of the North and the South and keep to this line or draw a line also between the affluent and the most deprived part of those societies within the North or within the South

Dr Anil Agarwal

I think this is a very fair question that has been asked. In fact in much of my writing I have tried to draw the difference really between the rich and the poor, and not so much between the North and the South. I have been writing a lot against the North only in the last one year because of all the global warming issues. But in all my analyses of any kind of management systems I would see very strong lines drawn between the rich and the poor because a lot of the environmental problems are caused even by the rich in our own countries. I have repeatedly made the point that if the WRI Report had pointed out that people like me are using too many cars and destroying the earth's atmosphere, believe me, I would have never responded against them however bad the mathematics or science or anything might have been. It is only because I got very mad at people saying that a poor farmer in Bangladesh or in Thailand or in West Bengal who has half an acre of land and is producing just about enough food to survive is producing methane which is destroying the earth's atmosphere. Even if that is so, that could not be compared with the emissions of anybody like me or anybody in New York who produces carbon dioxide because of their cars. I think that is a very very important point that was made and I would agree with it.

Valedictory Address

Kamal Nath
Ministry of Environment and Forests
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At the outset, I would like to congratulate the British Council Division for organizing this symposium on climate change which has, I am sure, led to an informed debate on the subject and resulted in better mutual understanding of the numerous aspects involved. I would also like to express my appreciation of the activities of the British Council in promoting cultural, educational, and technical co-operation between our two countries.

Recently, I had the pleasure of discussing with Mr Michael Heseltine in London the close co-operation between the UK and India in the environment sector, and I have been much encouraged by the prospect of further strengthening this relationship. It is heartening that on many issues, the UK and India delegations to the ongoing global negotiations on environmental issues share a common approach and similar perceptions.

A number of global environmental issues have been brought to the top of the environmental agenda in international deliberations during the last few years. Climate change is one such major issue which has been engaging a great deal of attention. This is because global warming caused by human activity and the resultant climate change are now perceived not only as distinct possibilities but are also known to be irreversible.

The environmental, economic, and social repercussions, for the present as well as future generations, need special attention, even though there is a considerable measure of scientific uncertainty regarding the extent and impact, particularly the regional impacts. It is too much to expect that this symposium would have cleared all the doubts about the extent and the regional impacts of climate change. But I do hope that participants now have a better understanding of the level of uncertainty which exists, and the kind of intensive and co-ordinated scientific research which is required to remove this uncertainty.

One fact, however, has emerged quite clearly—the threat of global warming

is caused not by emissions of greenhouse gases as such, but by the excessive levels of such emissions caused by the energy consumption of the rich and the affluent, whether directly or indirectly. A recognition of this fact, and the acceptance of remedial measures, which becomes self-evident by such recognition, must form the corner-stone of the response strategies that the world has to adopt in this area.

In the ultimate analysis, the measures are straightforward: those who are responsible for excessive emissions must take immediate action to reduce such emissions and thus restore the atmospheric balance. I may add that, on universally accepted principles of equity, excessive emissions have to be calculated on a per capita basis.

Unfortunately, there are repeated attempts—sometimes out of design, at other times out of ignorance–to create confusion about the main causes of climate change and therefore about the remedial measures required. Even in utter disregard of proven scientific data, fingers are pointed at cows and pigs as sources of methane, at biomass burning by the poor, at paddy fields, etc. All these activities, even put together, do not contribute more than a fraction of the greenhouse gases. How, then, can we think of laying the blame at the doorstep of the poor, much less of asking them to modify their simple lifestyles?

25% of the world's population consumes 75% of its energy. This gives a ratio of 1:9 in energy consumption in real terms between the developing and the developed countries. And, should we examine the per capita statistics, the imbalance of the scenario is thrown into startling relief.

At another level, deforestation is cited as a culprit and it is said that this leads to a loss of the sinks for carbon dioxide. There is no doubt that deforestation is undesirable for a variety of valid reasons such as disturbance in the atmospheric equilibrium. In India, we have laid down stringent regulations to prevent and check deforestation. In addition, ambitious afforestation and wastelands development programmes have been undertaken. I am happy and proud to say that satellite imagery shows that the green cover in India is, in fact, actually increasing. The international community is assisting us in our programmes. We will continue and expand our effort. We also welcome enhanced international support for this purpose. What we do not need are international regulatory mechanisms, whether for climate change or for forest management.

The second crucial consideration in dealing with climate change is the likelihood of adverse impacts on the less developed world. I am speaking of phenomena such as rise in sea levels and, especially in the context of the Indian subcontinent, a disruption in the monsoon pattern.

It has to be clearly understood that we have done nothing to create the problem. Besides, we stand to suffer the most because we do not have the financial or technical resources needed to divert from our current programmes for development. The

plight of billions of innocent people who could be displaced, physically or economically, or otherwise suffer from changes in the ecosystem, cannot possibly be ignored when we discuss the impacts of climate change and the possible responses. The Indian coastline, for example, has some of the largest cities in the world. A population of about 200 million lives along our coasts or survives on coastal activity. Who is to bear the burden if the sea rises and displaces this population?

Third, there is the question of technology. I am sure the developed economies can find ways and improve efficiency to see that the reduction in the emission of greenhouse gases does not hamper their growth rate. Considerable investments have already been made in research and development of technologies such as PFBC (pressurized fluidized bed combustion), CCP (combined cycle plant) and, ISTIGS (intercooled steam injected gas turbines). At the same time, emphasis has to be placed on non-conventional energy sources such as photovoltaic grids, wind energy, and energy from biomass to supplement energy conservation measures and improved energy efficiency in various systems.

The question really is: How, and on what terms, will such environmentally sound technology be shared with the developing countries, and in what manner? The various issues related to technology transfer are well understood in this forum, and I will not dwell on them any further.

I am aware that when the concerns I have mentioned are raised by the developing countries, they are often misunderstood as being uncaring or callous about the global environment. Nothing could be further from the truth. In India, for example, we fully share the international concern about the environment: about the ozone layer, about climate change, biological diversity, marine pollution, acid rain, hazardous chemicals, and wastes. We may have done nothing to create these problems; some of them do not affect us either, and from others we suffer more than the perpetrators. But we do perceive the global threats created by such phenomena and appreciate that quick, effective steps are required to deal with them.

At the national level, we have spared no effort in our policy direction, legislative framework, and administrative and institutional structures to ensure environmental protection. Effects on the atmosphere is one of the objectives included in our forest policy. We are in the process of enunciating a new and integrated environmental policy.

The level of income of a vast majority of our people still remains such as to place but a marginal demand on natural resources. Our values—partly out of tradition, partly out of necessity—ensure an incredible amount of recycling, great longevity for consumer goods, and minimum waste generation.

Even beyond this, we are perfectly willing to participate in efforts to correct environmental imbalances of a global nature. All we need is a guarantee that such efforts will not place additional economic burdens on our people, directly or